Thermal Management for PCs Based on the Boxed Pentium® Processor and the Boxed Pentium Processor with MMX™ Technology

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Introduction

This document is written for professional system integrators building PCs from industry accepted motherboards, chassis, and peripherals. It provides information and recommendations for thermal management in systems using the following Intel processors:

- Boxed Pentium® processors
- Boxed Pentium processors with MMX™ technology

It is assumed that the reader has a general knowledge of and experience with PC operation, integration, and thermal management. Integrators who follow the recommendations presented here can provide their customers with more reliable PCs and will see fewer customers returning with problems. (The term "Boxed Pentium processors" refers to processors packaged for use by system integrators.)

Thermal Management

Systems using Pentium processors and Pentium processors with MMX technology *all require thermal management*. The term "thermal management" refers to two major elements: a heatsink properly mounted to the processor, and effective airflow through the system chassis. The ultimate goal of thermal management is to keep the processor at or below its maximum operating temperature. For Pentium processors and Pentium processors with MMX technology, the maximum operating temperature is 70°C, measured in the center of the top of the processor package. A system with proper thermal management for a Boxed Pentium processor can be easily upgraded to a Pentium OverDrive® processor or a Pentium OverDrive processor with MMX technology.

Proper thermal management is achieved when heat is transferred from the processor to the system air, and the warm air is vented out of the system. Boxed Pentium processors and Boxed Pentium processors with MMX technology are shipped with a high-quality fan heatsink, which can effectively transfer processor heat to the system air. Some processors are shipped with a fan heatsink that is already attached with thermally conductive adhesive. Other processors are shipped with a fan heatsink that must be installed by the system integrator using the provided thermal grease and clip.

This document makes recommendations for installing the fan heatsink if it is not already attached, and for achieving good system airflow. It also provides a procedure for determining the effectiveness of a system's thermal management solution.

Installing a Fan Heatsink

Some Boxed Pentium processors and Boxed Pentium processors with MMX technology are shipped with a separate fan heatsink, clip, fan cable, and small quantity of thermal grease. These items should be used following the directions contained in the installation notes for the boxed processors. When properly installed, the fan heatsink and processor assembly appears as shown in Figure **1**.

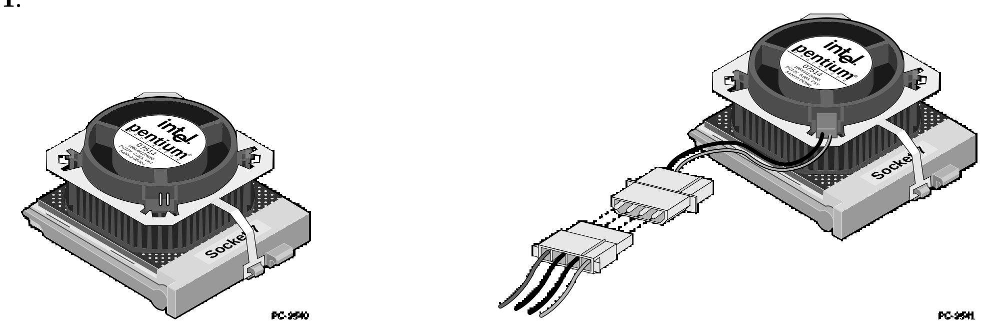

Figure 1. Boxed Pentium® Processor or Boxed Pentium Processor with MMX™ Technology with Fan Heatsink, Clip and Power Cable

A small amount of thermal grease mates the fan heatsink to the processor. This thermal grease aids in heat transfer and absorbs vibration. The clip tightly holds the fan heatsink to the processor, by connecting to mounting tabs on the socket. The fan cable provides power to the fan by connecting to a disk drive power connector.

Attached Fan Heatsink

Some Boxed Pentium processors and Boxed Pentium processors with MMX technology have a fan heatsink that is permanently attached with a thermally conductive adhesive. Again, the fan cable provides power to the fan, by connecting to a disk drive power connector.

Fan

Both boxed processors ship with a high-quality ball bearing fan that provides a good local air stream. This local air stream transfers heat from the heatsink to the air inside the system. Moving heat to the system air is half the task. Sufficient system airflow is also needed to exhaust the air. Without a steady stream of air through the system, the fan heatsink will recirculate warm air, and therefore may not cool the processor enough.

System Airflow

Chassis design, size and location of chassis air intake and exhaust vents, power supply fan capacity and venting, location of the processor socket, and placement of add-in cards and cables all determine system airflow. System integrators must ensure airflow through the system to allow the fan heatsink to work effectively. Proper attention to airflow when selecting subassemblies and building PCs is important for good thermal management and reliable system operation.

Two basic motherboard-chassis-power supply form factors are used by integrators: the Baby AT form factor, and the more recent ATX form factor.

In systems using Baby AT components, airflow is usually from front to back. Air enters the chassis from vents at the front and is drawn through the chassis by the power supply fan. The power supply fan exhausts the air through the back of the chassis. Figures 2 and 3 show the airflow through Baby AT systems.

The ATX form factor is a recent innovation to PC form factors. The ATX form factor simplifies assembly and upgrading of PCs, while improving the consistency of airflow to the processor. With regard to thermal management, ATX components differ from Baby AT components in that ATX power supplies typically draw air *in* to the chassis rather than venting out system air. Also, on an ATX motherboard, the processor socket is located close to the power supply, rather than to the front panel of the chassis. Because of these component differences, the airflow in ATX chassis usually flows from the back of the chassis, directly across the processor, and out through the front, side, and rear vents of the chassis. Figure 4 shows typical airflow through an ATX system.

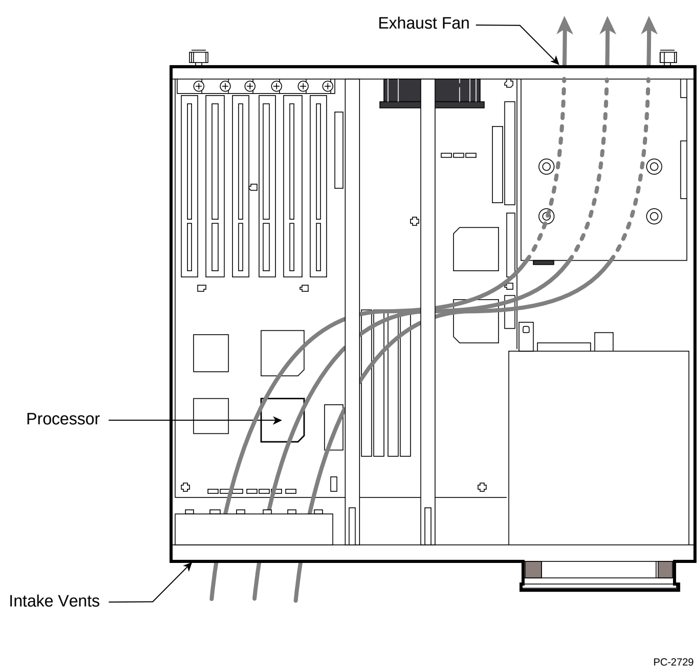

Figure 2. System Airflow through Baby AT Desktop Chassis (Top View)

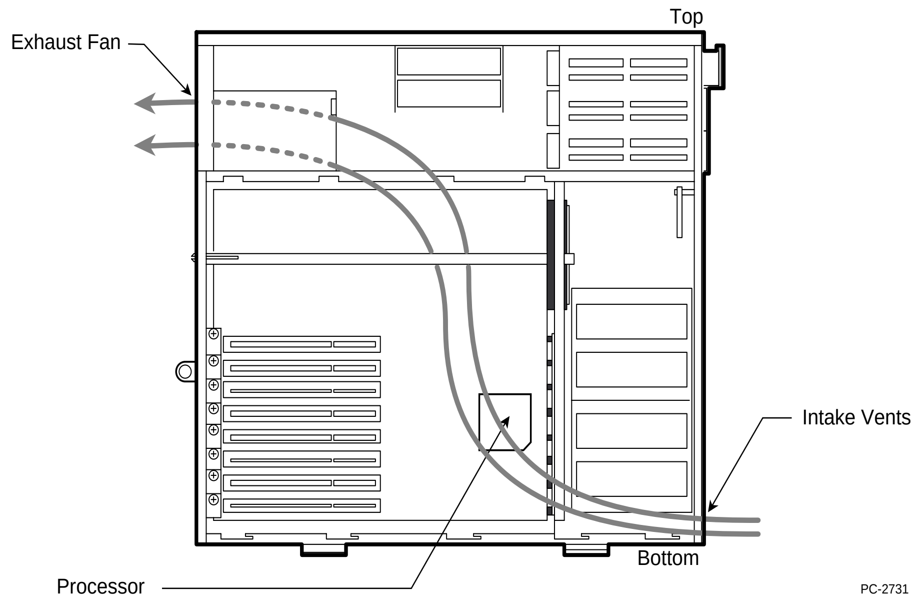

Figure 3. System Airflow through Baby AT Tower Chassis (Side View)

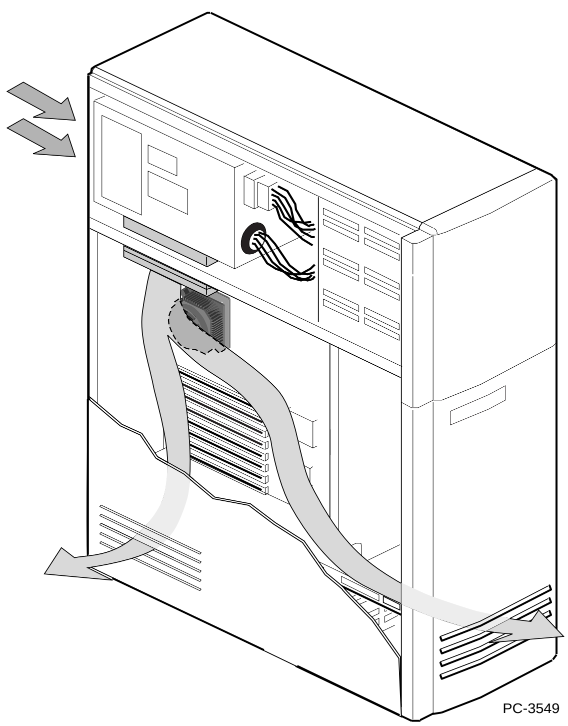

Figure 4. System Airflow through ATX Tower Chassis (side view)

The following is a list of guidelines to be used when integrating a system. Specific references to Baby AT and ATX components are made where necessary.

- **Chassis vents must be functional:** Integrators should be careful not to select chassis that contain only cosmetic vents. Cosmetic vents are designed to look like they allow air into the chassis, but no air (or little air) actually enters.

- **Chassis vents must not be excessive in quantity:** Chassis with excessive air vents should also be avoided. For example, if a Baby AT chassis has large air vents on all sides, most air enters near the power supply and then immediately exits through the power supply or nearby vents. Very little air flows over the processor and other components.

- **Chassis vents must be properly located:** Systems must have properly located intake and exhaust vents. The best location for air intakes allows air to enter the chassis and flow directly over the processor. Exhaust vents should be situated so that air flows on a path through the system, over various components, before exiting. Specific location of vents depends upon the type of chassis. For most desktop Baby AT systems, the processor is located near the front, and thus intake vents on the front panel work best. For Baby AT tower systems, intake vents on the bottom of the front panel work best. For ATX systems, exhaust vents should be located in both the bottom front and bottom rear of the chassis.

- **Power Supply Air Flow Direction:** PC power supplies contain a fan. It is important that the power supply fan draws air in the proper direction. For Baby AT systems, the power supply fan needs to act as an exhaust fan, venting system air outside the chassis. For ATX systems, the power supply fan typically acts as an intake fan, drawing air into the system. Some power supplies have markings noting airflow direction. Ensure that the proper power supply fan is used based upon the system form factor.

- **Power Supply Fan Strength:** Depending upon the type of power supply, the fan draws air either into or out of the chassis. If intake and exhaust vents are properly located, the power supply fan can draw enough air for most systems. If the air intake or exhaust is limited or restricted, however, the fan will not move much air. For some chassis in which the processor is running too warm, changing to a power supply with a stronger fan can greatly improve the airflow.

- **System Fan - Should It be Used?:** Some chassis may contain a system fan (in addition to the power supply fan) to facilitate airflow. A system fan is typically used with passive heatsinks. With fan heatsinks, a system fan can have mixed results. In some situations, a system fan improves system cooling. However, sometimes a system fan recirculates warm chassis air, thereby reducing the thermal performance of the fan heatsink. When using processors with fan heatsinks, rather than adding a system fan, it is generally a better solution to change to a power supply with a more powerful fan. Thermal testing both with a system fan and without the fan will reveal which configuration is best for a specific chassis.

- **System Fan Airflow Direction:** When using a system fan, ensure that it draws air in the same direction as the overall system airflow. For example, a system fan in a Baby AT system might act as an intake fan, pulling in additional air from the front chassis vents. A system fan in an ATX system, however, might act as an exhaust fan, pulling air from within the system out through the rear or front chassis vents

- **Protect Against Hot Spots**: A system may have a strong air flow, but still contain “hot spots.” Hot spots are areas within the chassis that are significantly warmer than the rest of the chassis air. Such areas can be created by improper positioning of the exhaust fan, adapter cards, cables, or chassis brackets and subassemblies, blocking the airflow within the system. To avoid hot spots, remember that hot air rises, and place exhaust fans accordingly, reposition full-length adapter cards, or use half-length cards, re-route and tie back cables, and ensure space around and over the processor.

Thermal Testing (System Checkout)

Differences in motherboards, power supplies, and chassis all affect the operating temperature of processors. Thermal testing is highly recommended when choosing a new supplier for motherboards or chassis, or when starting to use new products. Thermal testing can show integrators whether a specific chassis-power supply-motherboard configuration provides adequate airflow for the Boxed Pentium processor and the Boxed Pentium processor with MMX technology.

An easy method for performing thermal testing is to attach a thermal indicator label to the bottom of the processor before placing the processor in its socket. Install the processor and attach the chassis cover. Power up the system and exercise it for 1 hour. Power down the system, remove the cover, and allow the system to cool. Remove the processor from its socket and check the thermal indicator label. The label indicates the highest temperature range the processor reached during operation. Along with the room temperature, the thermal label temperature can be used in a calculation to verify the maximum operating temperature of the system (this calculation is described later).

Boxed Pentium processors and Boxed Pentium processors with MMX technology come in both plastic (PPGA) and ceramic (CPGA) packages. Thermal testing using a thermal indicator label must be done on a processor in a ceramic package. Thermal tests using processors in the plastic package will yield erroneous results.

Figure 5 shows a thermal indicator label. Each label has several temperature ranges that change from white to red at different temperature levels. Once a level has changed color, it stays that color. This feature allows the labels to record the maximum temperature reached during testing.

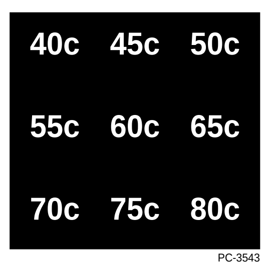

Figure 5. Thermal Indicator Label

In addition to the thermal labels, the equipment required for testing includes:

- A thermometer (to measure room temperature)
- The DOS EDIT.COM program on a system disk (disk boots to DOS). EDIT.COM must be from DOS 5.xx or 6.xx, not from another operating system.

The procedure for thermal testing is as follows:

Note: If you are testing a system with a variable-speed system fan, you must run the test at the maximum operating room temperature you have specified for the system.

1. To ensure maximum power consumption during the test, you must disable the system's automatic power-down modes or "green features." These features are controlled either within the system BIOS or by operating system drivers.

Make sure that the processor is cool enough before applying or removing a label. *If the system is powered on at the start of the test, wait at least 15 minutes after turning off power and removing the chassis cover.*

2. Place a thermal label on the bottom in the center of the processor package.

3. Figure 6 shows correct placement of the label on the processor.

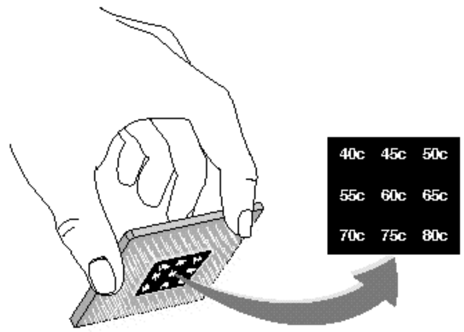

Figure 6. Ceramic Package Pentium Processor with Thermal Indicator Label

4. Install the processor and connect the fan heatsink power cable. (See Hint 1 to determine which processor should be tested.)

5. If you disconnected cables or removed boards to install the processor, replace them now. Quickly power up and power down the system to make sure the fan rotates. If the fan is not rotating, check the fan heatsink power connections, and do another quick check.

6. Attach chassis cover and replace cover screws.

7. If the system is formatted to boot to DOS, go to step 8. If the system doesn't boot DOS (for example it boots Windows* 95 or OS/2*) insert the bootable DOS disk with EDIT.COM into drive A.

8. Power up the PC. If the system has been assembled properly, and if the processor is properly installed and seated, the system boots to DOS.

9. Invoke DOS EDIT and select the FILE pull-down menu (ALT + F). Leaving the menu pulled down exercises the processor constantly, causing the processor to heat up rapidly.

10. Allow the menu to remain pulled down for 1 hour. This allows the entire system to heat up and stabilize. Record the room temperature at the end of the 1 hour period.

11. After recording the room temperature, power the system down. Remove the chassis cover.

Allow the system to cool at least 15 minutes.

12. Remove the processor and turn it over to examine the thermal label.

13. Record the thermal label's lowest temperature range that remained white. Remove the label when testing is complete. Labels cannot be used again.

Proceed to the next section to verify the maximum operating temperature for the system.

Testing Hints

Use the following hints to reduce the need for additional thermal testing.

1. As mentioned earlier, the processors in the PPGA package cannot be thermally tested with the thermal indicator label. The 233-MHz Boxed Pentium processor with MMX technology and the 200-MHz Boxed Pentium processor use only the plastic (PPGA) package. For these processors, use a ceramic (CPGA) 200-MHz Boxed Pentium processor with MMX technology or a ceramic 166-MHz Boxed Pentium processor for thermal testing.

   When testing a system that supports more than one speed of processor, test with the motherboard configured for the CPGA processor that generates the most heat (dissipates the most power). By testing the warmest processor supported, you need not explicitly test the processors that generate less heat with the same motherboard and chassis configuration.

   Lower-speed processors usually generate less heat than higher-speed processors. However, there are exceptions when processors are based on different silicon technologies. To ensure selection of the appropriate processor, refer to Table 1 for power dissipation numbers for Boxed Pentium processors and Table 2 for power dissipation numbers for the Boxed Pentium processor with MMX technology.

Table 1. Pentium® Processor Speed vs. Maximum Active Power Dissipation

Boxed Pentium® Processor Speed (Package)	Maximum Active Power Dissipation
133 MHz (CPGA)	11.2 W
150 MHz (CPGA)	11.6 W
166 MHz (CPGA)	14.5 W
200 MHz (PPGA)	15.5 W

Table 2. Pentium® Processor with MMX™ Technology Speed vs. Maximum Active Power Dissipation

Boxed Pentium® Processor with MMX™ Technology Speed (Package)	Maximum Active Power Dissipation
166 MHz (PPGA)	13.1 W
166 MHz (CPGA)	13.1 W
200 MHz (PPGA)	15.7 W
200 MHz (CPGA)	15.7 W
233 MHz (PPGA)	17.0 W

2. Thermal checkout with a new motherboard is unnecessary if all of the following conditions are met:
   - The new motherboard is used with a previously tested chassis that worked with a similar motherboard. The previous test showed the configuration to provide adequate airflow.
   - The processor is located in approximately the same place on both motherboards.
   - A processor with the same or lower power dissipation will be used on the new motherboard.

3. Most systems are upgraded (additional RAM, adapter cards, drives, etc.) sometime during their life. Integrators should test systems with some expansion cards installed in order to simulate a system that has been upgraded. A thermal management solution that works well in a system that is heavily loaded need not be retested for lightly loaded configurations.

Calculation to Verify a System's Thermal Management Solution

This section explains how to determine whether a *system* meets the maximum operating temperature intended while keeping *the processor* within its maximum operating range. The result of this process shows whether system airflow needs to be improved or the system's maximum operating temperature needs to be revised in order to produce a more reliable system. (An example is provided at the end of this section.)

The first step is to select a maximum operating room temperature for the system. A common value for systems where air conditioning is *not* available is 40°C. A common value for systems where air conditioning *is* available is 35°C. Choose a value that is right for your customer. Write this value on line A below.

Write the room temperature recorded after testing on line B below. Subtract line B from line A and write the result on line C. This difference compensates for the fact that the test was most likely conducted in a room that is cooler than the system's maximum operating temperature.

(Appendix A contains a table for converting between Fahrenheit and Celsius scales.)

A.	_ _ _ _ _	Maximum operating temperature, typically 35° C or 40° C
B.	- _________	Room temperature °C at end of test
C.	_ _ _ _ _	Difference between test environment temperature and maximum operating temperature

Write the temperature recorded from the indicator label (lowest temperature range that remained white) on line D below. Copy the number from line C to line E below. Add line D and line E and write the sum on line F. This number represents the highest temperature for the *bottom* of the processor when the system is used at its specified maximum operating room temperature. There is one more step.

Since the top of the processor gets warmer than the bottom, we need to take that difference into account. Add 5°C to the value on line F and write the sum on line G.

D.	_ _ _ _ _	Temperature from label
E.	+ _______	Line C from above
F.	_ _ _ _ _	Lowest temperature range indicator that remained white through the thermal testing
	+ 5°C	Top to bottom difference
G.	_ _ _ _ _	Calculated processor case temperature

The value on line G represents the package case temperature of the processor when the system is operated in its warmest environment. Processors should not be run at temperatures higher than their maximum specified operating temperature or failures may occur. (This maximum temperature for a Pentium processor or a Pentium processor with MMX technology is 70°C.) If line G reveals that the *processor* reached a temperature higher than its maximum operating range, then action is required. Either the system airflow must be significantly improved, or the *system's* maximum operating room temperature must be lowered.

The specification for the Pentium processor and the Pentium processor with MMX technology states the maximum case temperature to be 70°C. Therefore, if the number on line G is less than or equal to 70°C, the system will keep the Boxed Pentium processor or the Boxed Pentium processor with MMX technology within specification, even if the system is operated in its warmest environment.

To summarize:

If the value on line G is greater than 70°C, there are two options:

1. Improve system airflow to bring the processor's temperature down (follow the recommendations made earlier). Then retest the system using another thermal label.
2. Choose a lower maximum operating room temperature for the system. Bear in mind the customer and the system's typical environment.

After implementing either option, you must recalculate the thermal calculation to verify the solution.

An example thermal calculation is provided below:

Example

This example assumes that a system with a ceramic 200-MHz Pentium processor with MMX technology is being tested. The intended maximum room temperature for the system is 40°C. The room temperature during the test is 28°C. The first three numbers (40°C, 45°C, 50°C) on the thermal indicator label change color but the 55°C dot stays white.

A) 40 intended maximum room temperature for system
B) - 28 actual room temperature during testing
C) 12 difference

D) 55 maximum processor temperature during testing (lowest white dot)
E) + 12 difference from first calculation (C)
F) 67 maximum temperature on bottom of processor
+5 difference between bottom and top of processor
G) 72 maximum processor temperature in system's maximum room temperature

Notice that 72°C is above the Boxed Pentium processor's maximum case temperature. Modifications should be made to the airflow of this system, or a lower maximum operating temperature should be set for the system.

If the maximum operating temperature is lowered to 35°C (a value typical of an air-conditioned environment) the calculated value of G is 61°C. Then if a 200-MHz Boxed Pentium processor with MMX technology were installed in the system, the processor would run within specifications. Of course, when the system is sold to the end customer, the maximum operating temperature should be clearly stated to the customer.

Appendix A

The following table is provided to help convert degrees Fahrenheit to degrees Celsius.

°F	°C	Notes
59.0	15	
60.8	16	
62.6	17	
64.4	18	
66.2	19	
68.0	20	
69.8	21	
71.6	22	Note 1
73.4	23	
75.2	24	
77.0	25	
78.8	26	
80.6	27	
82.4	28	
84.2	29	
86.0	30	
87.8	31	
89.6	32	
91.4	33	
93.2	34	
95.0	35	Note 2
96.8	36	
98.6	37	
100.4	38	
102.2	39	
104.0	40	Note 3
105.8	41	
107.6	42	
109.4	43	
111.2	44	
113.0	45	
114.8	46	
116.6	47	

°F	°C	Notes
118.4	48	
120.2	49	
122.0	50	
123.8	51	
125.6	52	
127.4	53	
129.2	54	
131.0	55	
132.8	56	
134.6	57	
136.4	58	
138.2	59	
140.0	60	
141.8	61	
143.6	62	
145.4	63	
147.2	64	
149.0	65	
150.8	66	
152.6	67	
154.4	68	
156.2	69	
158.0	70	
159.8	71	
161.6	72	
163.4	73	
165.2	74	
167.0	75	
168.8	76	
170.6	77	
172.4	78	
174.2	79	
176.0	80	

Note 1: Typical office room temperature
Note 2: Typical maximum operating room temperature for a system in an air-conditioned environment
Note 3: Typical maximum operating room temperature for a system in a non-air-conditioned environment