

Heat Dissipation of the TriStar & TriStar MPPT Controllers inside Enclosures



ABSTRACT: Since power electronics generate heat during operation, it is very important to consider thermal management as a part of the overall system design. When power electronics are operated inside an enclosure, heat is trapped and this can cause a significant temperature rise of the enclosure's internal air. High temperatures affect operating lifetimes for electronics and lead to thermal derating and shutdowns. Since the controllers can be the hottest during peak conditions when they are working the hardest, thermal shutdowns due to a poor system design can significantly reduce the amount of energy harvested. This paper shows how to calculate the heat dissipation for Morningstar's TriStar (PWM) and TriStar MPPT controllers, determine the air temperature rise inside an enclosure, and then determine the resulting heat sink temperature of the controller to ensure it is below its operating limits. There are also recommendations for how to reduce operating temperatures. With this information, system designers can make good decisions regarding thermal management and system design when installing Morningstar controllers inside enclosures.

Heat Dissipation inside an Enclosure

Morningstar's controllers and inverters are very often installed within an outdoor enclosure. Many of these installations are located in warm climates where overheating of equipment inside the enclosure can become a concern. Since power electronic components will produce heat that can accumulate inside the enclosure, it is important to determine the effect of this heating on the temperature inside that enclosure.

This paper shows how to calculate the heat dissipation for Morningstar's [TriStar](#) (PWM) and [TriStar MPPT](#) solar charge controllers, determine the air temperature rise inside an enclosure, and then determine the resulting heat sink temperature of the controller to ensure it is below its operating limits. There are also recommendations for how to reduce operating temperatures. With this information, system designers can make good decisions regarding thermal management and system design when installing Morningstar controllers inside enclosures.

Background

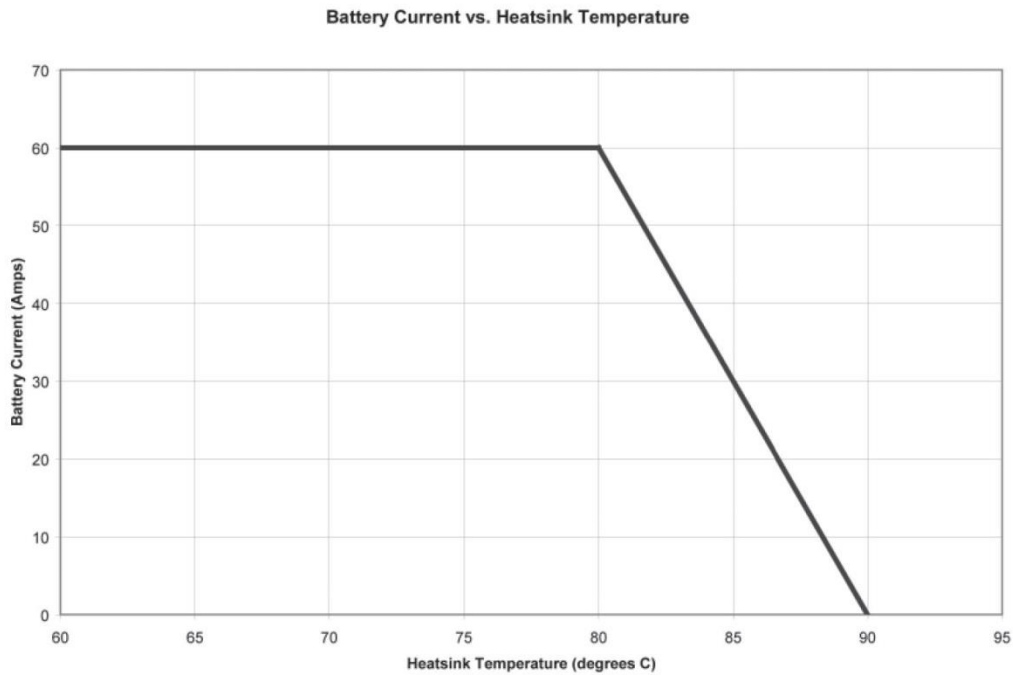
Morningstar's robust thermal design dissipates heat quickly and reduces the operating temperature of the controller's key electronic components. The amount of heat dissipated is equivalent to how much energy is being lost during power transfer inside the controller. The higher the controller efficiency, the more usable energy is preserved and the less heat is generated.

Morningstar's high efficiency controllers and inverters are frequently installed in an outdoor enclosure in hot climates where overheating of equipment inside the enclosure is a concern. Therefore, it is often critical to determine the air temperature rise inside the enclosure and the maximum temperature of the electronics. This paper discusses how to calculate the heat dissipation for Morningstar's TriStar (PWM) and TriStar MPPT controllers, determine how that heat dissipation will affect the air temperature inside an enclosure, and finally calculate the highest heat sink temperature of the controller to ensure it is below operating limits.

Proper system design should consider the worst case conditions to ensure maximum temperatures are not exceeded with ample margin. However, in the case that maximum temperatures are exceeded, the controllers are programmed to derate power levels to reduce temperatures and protect the components. Below is a graph of the derating curve for the TS-MPPT-45 and TS-MPPT-60.



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The TS-45 and TS-60 thermally shut down at 95C heat sink temperature after reducing charging current. As can be seen above, the TS-MPPT-45 and TS-MPPT-60 start to thermally derate the charging current at 80C heat sink temperature. Using the following steps you can determine the worst case temperature of the controller when mounted inside an enclosure to ensure it doesn't exceed these temperatures and cause shut down or derating.

Overview of Steps

When installing a Morningstar controller inside an enclosure you should ensure good thermal design by following these steps which are explained in further detail below:

1. Determine the maximum heat dissipation of the controller.
2. Determine the temperature rise of the enclosure's internal air.
3. Determine the heat sink temperature rise of the Morningstar Controller.
4. Determine the maximum heat sink temperature of the Morningstar controller and compare to derating limits.

1. Determine the maximum heat dissipation of the controller.

To calculate the heat dissipation of a TriStar (PWM) or TriStar MPPT controller it is first necessary to determine the power losses during operation using calculations that are dependent on controller model and operating parameters.



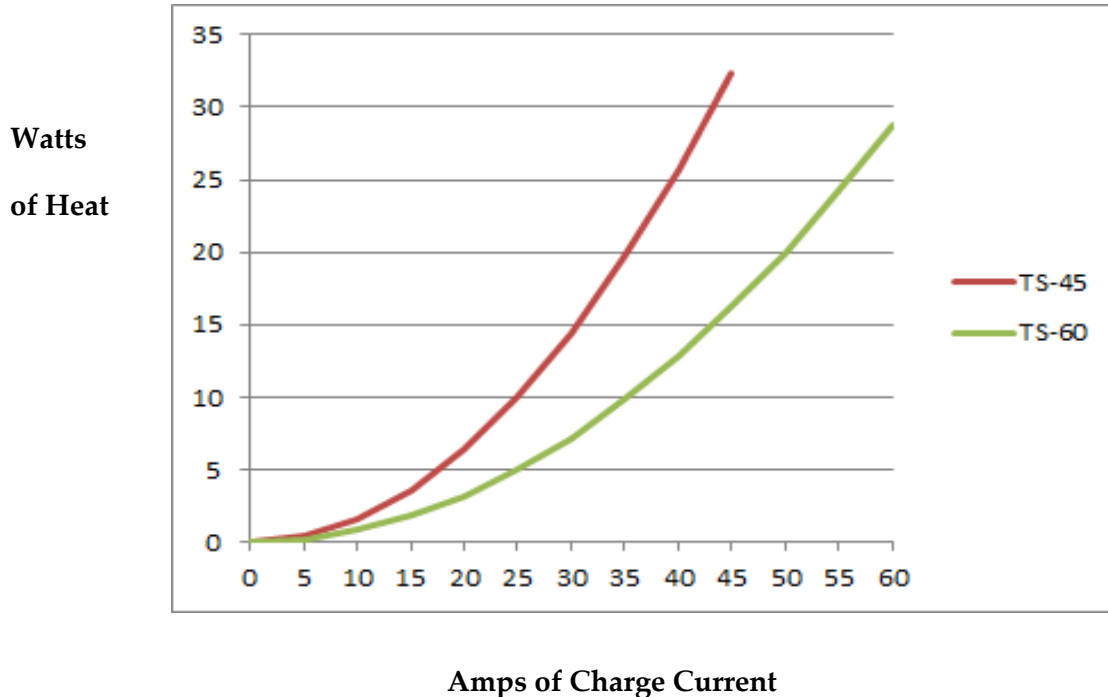
Loss (heat) Calculations for TriStar (PWM) Controllers

The TriStar controller uses Pulse Width Modulation (PWM) to manage the amount of current allowed into the battery bank during charge control. It does this by adjusting the amount of time the controller's power transistors (MOSFETs) are spent "on" and "off" during each switching cycle. These MOSFETs dissipate heat both when they are "on" as well as during the transition state when switching on and off (switching losses during PWM absorption stage).

Using calculations dependent on how many MOSFETs are used and their configuration inside the device, Morningstar has derived that at full power the TriStar-60Amp controller (model TS-60) and TriStar-45Amp controller (model TS-45) will have a maximum of 28.8 Watts and 32.4 Watts of thermal loss, respectively. Because fewer MOSFETs are used in the TS-45 controller, it produces slightly more heat due to each MOSFET carrying more share of the available current. The TS-60 controller runs cooler than the TS-45 controller and can be a desirable choice in high temperature applications, even if TS-60 controller is a larger capacity than what is needed.

Below is a graph of the thermal loss of each TriStar (PWM) model (TS-45 and TS-60) with respect to charge current. Using this graph it is possible to determine the maximum heating for any given current level. Typically, the array's short circuit current (I_{sc}) is used as the maximum output current of the controller.

TriStar PWM Thermal Heating Curves (Amps vs. Watts)



Loss (heat) Calculations for TriStar-MPPT Controllers

Morningstar publishes each product's efficiency curve(s) in their respective operating manual. The TriStar MPPT (TS-MPPT) controller manual includes three efficiency graphs in Section 8.0: Specifications, one for each nominal battery voltage: 12V, 24V and 48V. (See also Appendix 1 in this document.) Each graph has 4 curves. Each curve represents a different PV operating voltage (V_{mp}). The X-axis is the Output Power and the Y-axis is the corresponding Controller Efficiency.

Using the appropriate graph for system nominal voltage, it is fairly simple to determine the controller efficiency for a given array Wattage. It may be necessary to consider the Ambient temperature when determining array voltages and power levels because higher temperatures decrease voltage of the PV array. Other factors can also play a role. The STC power level of the array will typically be a conservative estimate especially during warmer operating temperatures. For systems installed in heated buildings cold temperature adjustment may also be considered.

By knowing the efficiency and PV power level, the thermal loss (in Watts) is calculated as follows: **Thermal Dissipation = (100 - Efficiency) X Power**

This efficiency loss in terms of power determines the amount of heat dissipation for the TriStar MPPT controller inside an enclosure.

2. Determine the temperature rise of the enclosure's internal air.

Enclosure heat dissipation information for electrical equipment is available from Hoffman Enclosure's paper on "[Heat Dissipation in Electrical Enclosures](#)".

Internal air temperature rise calculations

- Determine the type of enclosure:
 - Unfinished Aluminum and Stainless Steel Enclosures
 - Painted Metallic and Non-metallic Enclosures
- Determine the Surface Area (feet²) = $2[(W \times D) + (W \times H) + (D \times H)] \div 144$ (Dimensions = W" X D" X H") Note: unexposed surface areas should be subtracted
- Determine the sum of all the thermal heating inside the enclosure in Watts
- Calculate the Watts / Square Foot of Surface Area = Total Watts / Surface Area
- Use the graph to determine the Temperature Rise (ΔT)
- Take into account other factors:
 - Direct Sunlight (should be avoided)
 - Indirect Solar Heating
 - Wind (may not always be present)
- Safety margin in critical applications (25%)



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3. Determine the heat sink temperature rise of the Morningstar Controller.

Graphs of the heat sink temperature rise vs heat dissipation for the TriStar and TriStar MPPT controllers are provided in Appendix 3. Using the heat dissipation found in step 1, the heat sink temperature rise of the controller can be found using these curves.

4. Finally, determine the maximum heat sink temperature of the Morningstar controller and compare to derating limits.

This final step is simply adding the highest expected outdoor air temperature, temperature rise of the enclosure, and the heat sink temperature rise of the controller found in the previous steps. This sum is the highest heat sink temperature, which should not exceed 90C for the TS-45 and TS-60 and 80C for the TS-MPPT-45 and TS-MPPT-60.

Sample Calculations

System Parameters

Array Size = 1600 Watts

8 X 200W Modules in Parallel

System Voltage: 24V Nominal

Hottest Record Temperature = 36°C

Enclosure: 15" X 12" X 10" (painted enclosure) $I_{sc} = 5.81A$

Roof mounted with 8" Standoffs (Cell Temp = +25°C above Ambient Temp)

Thermal Dissipation from other components in the enclosure = 10 Watts Maximum

Module STC Ratings & Temperature Coefficients

$P_{max} = 200W$

$V_{mp} = 36.7V$ Temp Coef. of $P_{mp} = -0.45 \text{ } \%/^{\circ}C$

$I_{mp} = 5.45A$ Temp Coef. of $V_{oc} = -0.34 \text{ } \%/^{\circ}C$

$V_{oc} = 45.5V$ Temp Coef. of $V_{mp} = -0.47 \text{ } \%/^{\circ}C$

Step 1: Power/Heat Dissipation

Using a TriStar Controller (model TS-60)*



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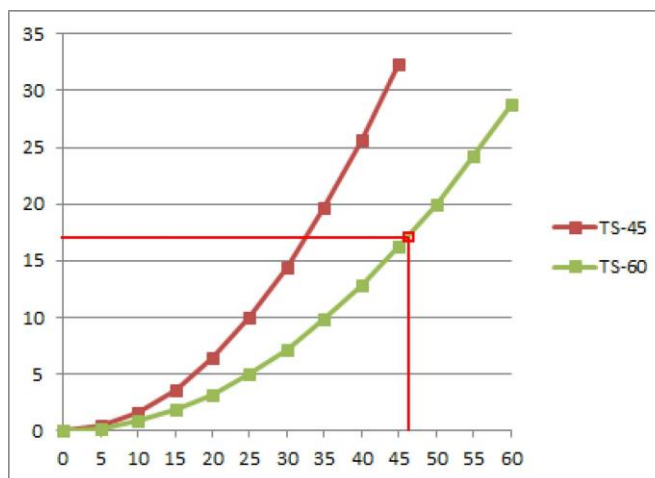
A: Determine Maximum Operating Current

Array $I_{sc} = 8 \times 5.81A = 46.5A$
(Advanced designers can calculate current based on temperature or tilt.)

B: Use the Thermal Heating Curve to Determine Thermal Heating

Use Array I_{sc} and the curve for the TS-60

With maximum current = 46.5A



TriStar Thermal Heating Curves (Amps vs. Watts)

Thermal dissipation = 17 Watts

*Because fewer MOSFETs are used in the TS-45 controller, it produces slightly more heat due to each MOSFET carrying more share of the available current. The TS-60 controller runs cooler than the TS-45 controller and can be a desirable choice in high temperature applications, even if TS-60 controller is a larger capacity than what is needed.

Using a TriStar MPPT Controller (model TS-MPPT-60)

Assuming the same array (above) is used with a TriStar MPPT controller, the calculations for Heat Dissipation are different.

A. Determine the operating temperature in hot conditions

$$\text{Maximum Cell Temp} = \text{Ambient Temp} + \text{Cell Heating} = 36^{\circ}\text{C} + 25^{\circ}\text{C} = 61^{\circ}\text{C}$$

B. Calculation of V_{mp} during hottest conditions

$$V_{mp} \text{ adjusted for temperature} = V_{mp} (\text{STC}) \times [1 + (\text{Cell Temp} - \text{STC Temp}) \times (\text{Temp Coef. of } V_{mp})]$$

$$\text{Note: Cell Temp} = \text{Ambient Temp} + \text{Cell Heating Conditions} = 36^{\circ}\text{C} + 25^{\circ}\text{C} = 61^{\circ}\text{C}$$

$$V_{mp} @ 36^{\circ}\text{C} = 36.7V [1 + (61^{\circ}\text{C} - 25^{\circ}\text{C}) \times (-0.0047/^{\circ}\text{C})]$$

$$= 36.7V \times [1 + (36^{\circ}\text{C}) \times (-0.0047/^{\circ}\text{C})]$$

$$= 36.7V \times [1 + (-0.1692)]$$

$$= 36.7V \times (.8308)$$

$$= 30.5V$$



Heat Dissipation of the TriStar and TriStar MPPT Controllers inside Enclosures

C. Calculation of Maximum Power (Pmp) during hottest conditions

Pmp adjusted for temperature = Pmp (STC) [(1 + (Cell Temp - STC Temp) X (Temp Coef. of Pmp)]

$$\text{Pmp @ } 45^{\circ}\text{C} = 1600\text{W} [1 + (61^{\circ}\text{C} - 25^{\circ}\text{C}) \times (-0.0045/^{\circ}\text{C})]$$

$$= 1600\text{W} \times [1 + (36^{\circ}\text{C}) \times (-0.0045/^{\circ}\text{C})]$$

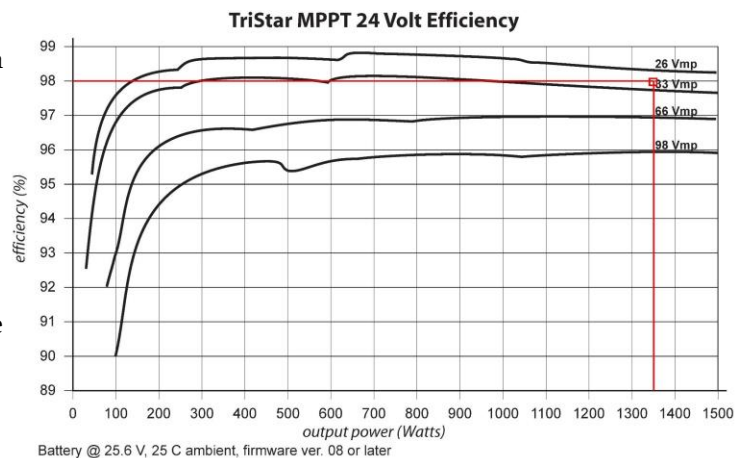
$$= 1600\text{W} \times [1 + (-0.162)]$$

$$= 1600\text{W} \times (.838)$$

$$= 1341\text{W}$$

D. Use the efficiency graph to determine the controller efficiency

- Section 8.0: Specifications of the TriStar MPPT manual includes a graph of the efficiency for a 24Vdc nominal battery system
- Use the calculated Vmp and Pmp during warm conditions.
 - Vmp = 30.5V (from calculation above)
 - Efficiency is between the 26V and 33V curves but closer to 33V line
 - Pmp = 1341W
 - Efficiency = 98%



E. Calculate Thermal Loss of TS-MPPT Controller

$$\text{Thermal Dissipation} = (100 - \text{Efficiency}) \times \text{Power} = (1 - .98) \times 1341 = .02 \times 1341 = 27 \text{ Watts}$$

Step 2: Determine the Temperature Rise of the Enclosure

A. Type of Enclosure

Painted Metallic

B. Surface Area

$$2 \times [(15 \times 12) + (15 \times 10) + (12 \times 10)] \div 144 = 6.25 \text{ ft}^2$$

C. Sum of all Thermal Heating

For the TS-60 controller: 17 Watts + 10 Watts = 27 Watts Total

For the TS-MPPT-60 controller: 27 Watts + 10 Watts = 37 Watts Total



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D. Calculate Watts / ft² of Surface Area

For the TS-60 controller: $27 \text{ Watts} / 6.25 \text{ ft}^2 = 4.3 \text{ Watts/ft}^2$

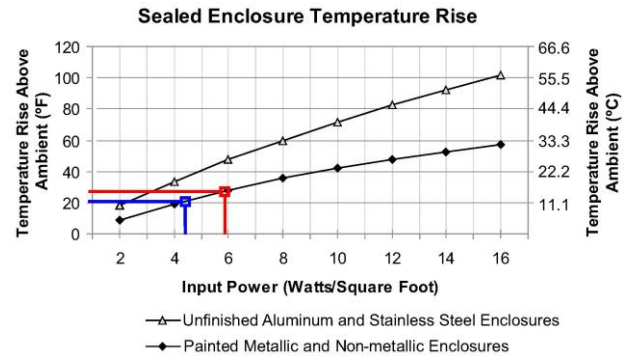
For the TS-MPPT-60 controller: $37 \text{ Watts} / 6.25 \text{ ft}^2 = 5.9 \text{ Watts/ft}^2$

E. Calculate the Temperature Rise (ΔT)

(Sealed Enclosure)

Find the [Hoffman Enclosure data for Painted Metallic](#) (Ref: Graph on the first page of the Hoffman Paper).

Sealed Enclosure Temperature Rise (ΔT)



Step 2 Results:

For the TS-60 (**Blue**) controller = 12°C rise in temperature above outside Ambient temperature.

For the TS-MPPT-60 (**Red**) controller = 15°C rise in temperature above outside Ambient temperature.

Step 3. Determine the Heat Sink Temperature Rise of the Morningstar Controller.

Using the heat dissipations from step 1 and the heat sink temperature rise curves in Appendix 3, the heat sink temperature rise of the controller can be determined.

For the TS-60, the heat dissipation was determined to be 17 W. If we assume it is vertically mounted inside the enclosure and using the appropriate graph for the TS-60 temperature rise in Appendix 3, the resulting heat sink temperature rise is approximately 25°C.

For the TS-MPPT-60, the heat dissipation was determined to be 27W. Using the appropriate graph in Appendix 3, the resulting heat sink temperature rise is approximately 23°C.

Step 4. Determine the Maximum Heat Sink Temperature of the Morningstar Controller and compare to derating limits.

Max Heat Sink Temperature = Max Outdoor Ambient + Max Enclosure Temperature Rise + Max Controller Heat Sink Temperature Rise.

For the TS-60 example:

$$\text{Max Heat Sink Temperature} = 36\text{C} + 12\text{C} + 25\text{C} = 73\text{C}$$

Since $73\text{C} < 90\text{C}$, which is the derating temperature for the TS-60, this is an acceptable system thermal design with sufficient margin.

For the TS-MPPT-60 example:

$$\text{Max Heat Sink Temperature} = 36\text{C} + 15\text{C} + 23\text{C} = 74\text{C}.$$

Since $74\text{C} < 80\text{C}$, which is the derating temperature for the TS-MPPT-60, this is an acceptable -to- marginal system thermal design.

It is worth pointing out that if a 120mm axial 75CFM fan were used in each case, the temperatures would be much lower. Determined from the "Fan cooled" line on the graphs.*

For the TS-60 example if a fan were used, the heatsink temperature rise would be only 8C.

For the TS-MPPT-60 example if a fan were used, the heatsink temperature rise would be only 9C.

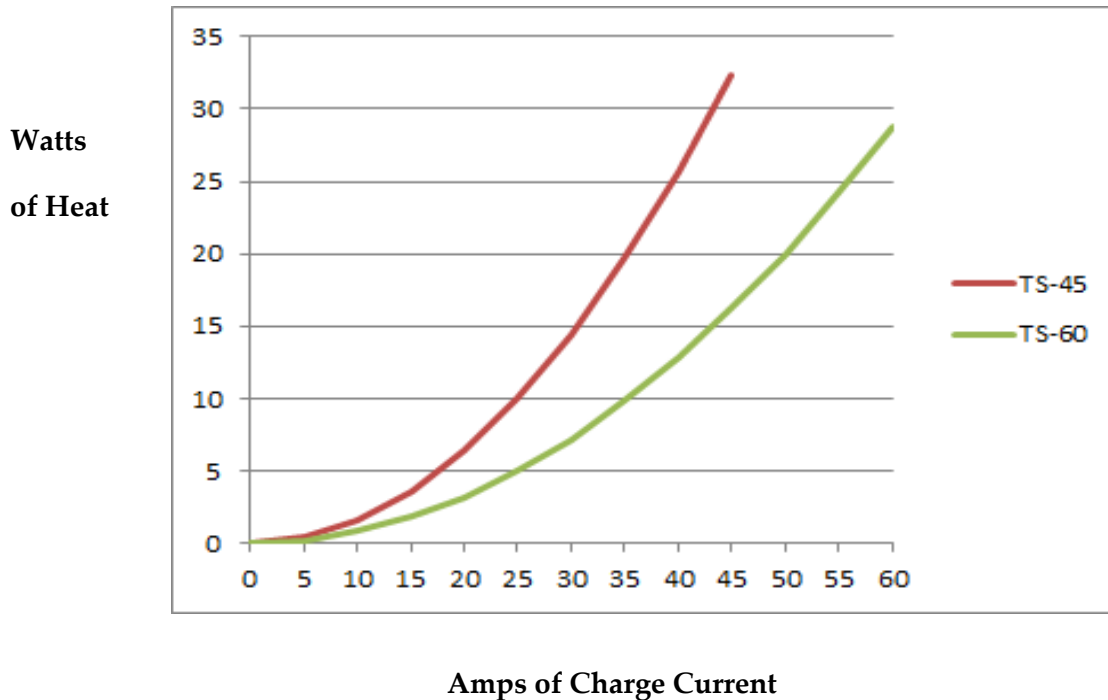
The resulting max heatsink temperatures would be 56C and 60C respectively.

Since the TS-MPPT-60 example is marginal, it might be worth adding a fan as an extra precaution. Morningstar's Relay Driver (RD-1) with a relay could be used to control a fan and cycle it as needed during high temperature periods.

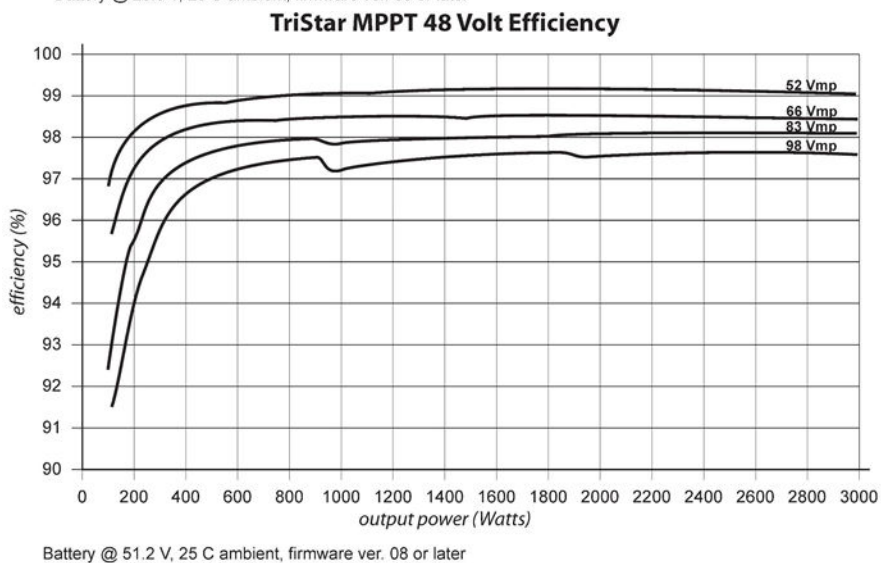
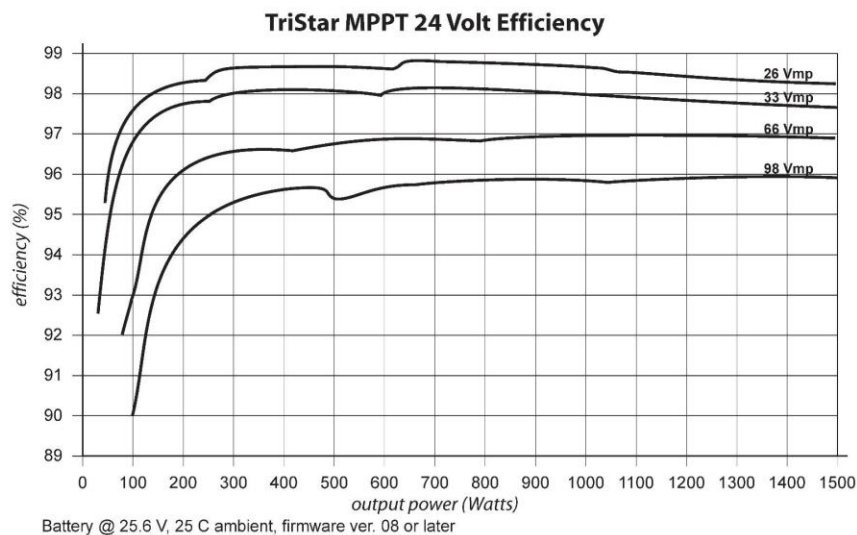
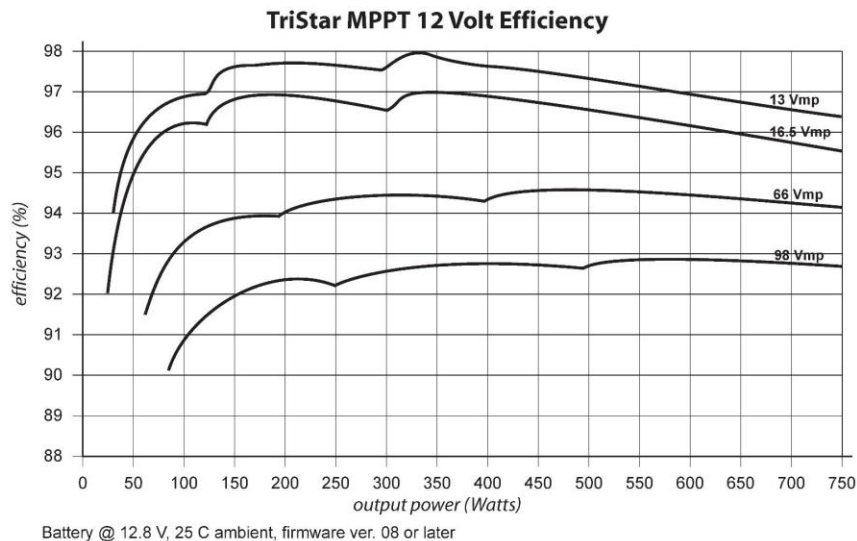
* Note: Fan calculations do not include the calculation of additional heat which will be introduced into the enclosure due to additional electronic heating from fan. Once determined it can be added to the total thermal dissipation from Step 1.

Appendix 1: TriStar 45 and 60 Thermal Dissipation Curves

TriStar PWM Thermal Heating Curves (Amps vs. Watts)



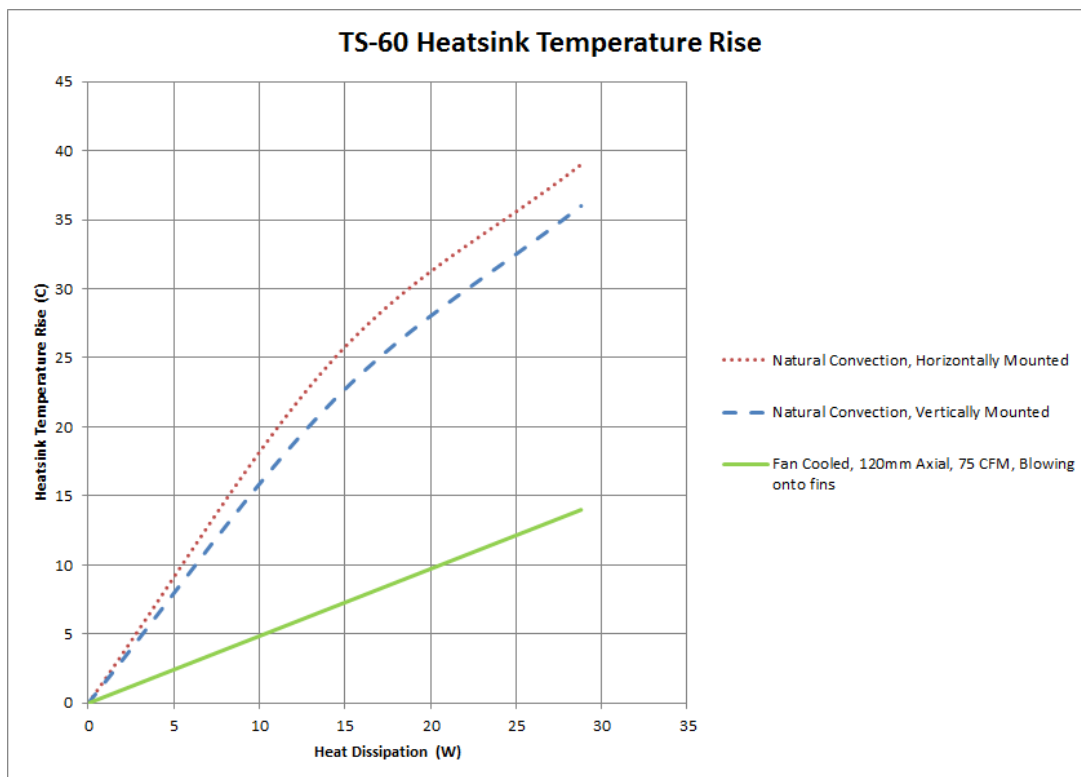
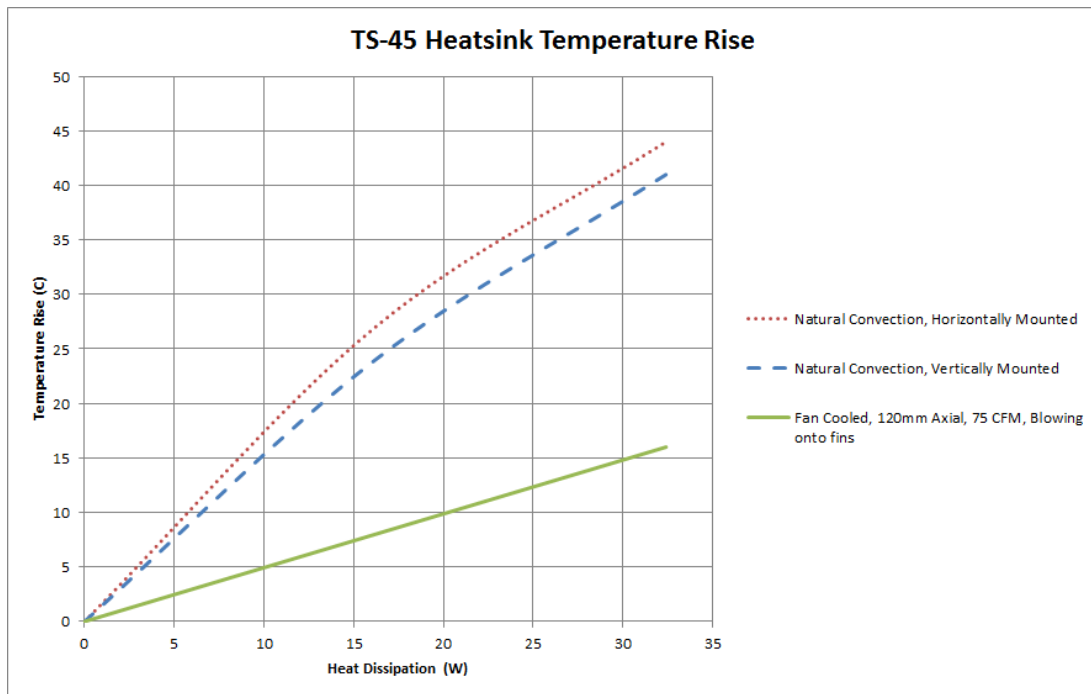
Appendix 2: TriStar MPPT Efficiency Curves



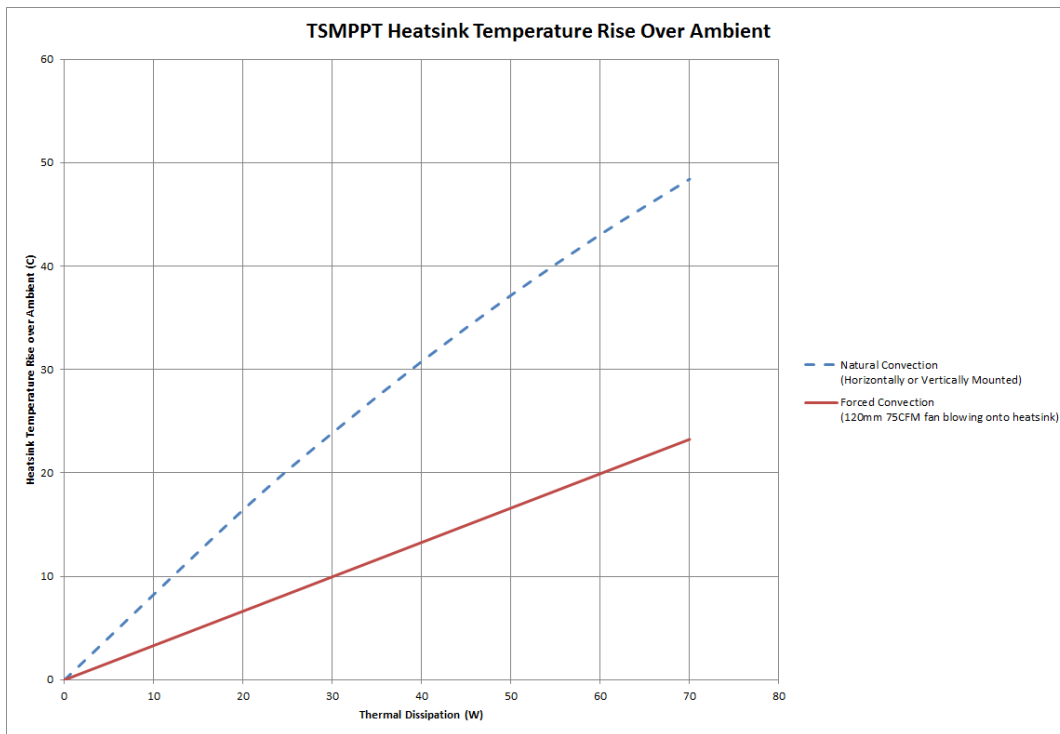
Heat Dissipation of the TriStar and TriStar MPPT Controllers inside Enclosures

Appendix 3: TS-45, T-60, and TriStar MPPT Heatsink Temperature Rise vs Thermal Dissipation

Note: Horizontal mounting refers to mounting with the fins normal to the ground not parallel. See Appendix 4 for illustrations of these orientations.



Heat Dissipation of the TriStar and TriStar MPPT Controllers inside Enclosures

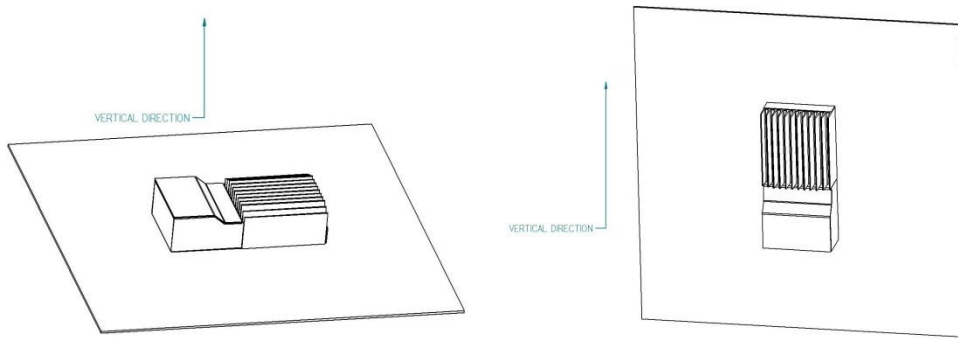


Appendix 4: Tips and Suggestions

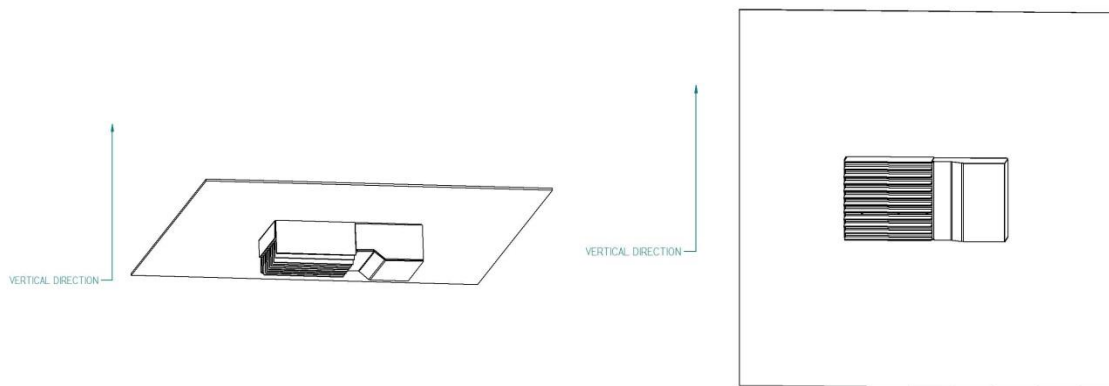
- When mounting inside an enclosure, ensure proper clearance between the heatsink fins and the enclosure walls. Inside an enclosure Morningstar recommends at least 6" of clearance from the top and end of the heatsink and 1" from the sides.
- Due to natural convection, the air at the bottom of a sealed enclosure (surface closest to the ground when mounted) can be several degrees cooler than at the top, so it is better to mount it toward the bottom of the enclosure.
- The controllers provide similar cooling performance when mounted horizontally (fins normal to ground, not parallel, and pointing upward - see proper mounting orientations below) or vertically. So it may make sense to mount the controller horizontally at the bottom of the enclosure with adequate clearance from the fins.
- As the curves in Appendix 3 show, a fan can be added to significantly reduce the temperature rise of the controller. If there is limited free space inside the enclosure for natural convection airflow, a fan is highly recommended. The fan airflow should be pointed toward the controller's heatsink for maximum effectiveness inside a sealed enclosure. A typical 120mm axial fan adds a modest (several Watts) of heat to the enclosure internal air space, but on balance there will likely be a lower enclosure air temperature due to the enhanced heat transfer to the enclosure walls from the extra turbulence that forced convection provides. In addition, a fan will mix the enclosure air and reduce temperature gradients, which cause components mounted at the top of the enclosure to see much higher temperatures than components mounted toward the bottom.
- A thermostat or Morningstar's Relay Driver (RD-1) with a relay can be used to control a fan and cycle it as needed during high temperature periods. The RD-1 can be set to be controlled according to the controller's heat sink temperature.
- Do not use a non-ventilated enclosure if possible
- Do not locate the enclosure in direct sunlight
- Use a larger enclosure with more surface area
- Add Ventilation
- Use a Solar Shielding Reflective material

Heat Dissipation of the TriStar and TriStar MPPT Controllers inside Enclosures

Proper Mounting Orientations



Improper Mounting Orientations - NEVER MOUNT IN THESE ORIENTATIONS!



To learn more about Morningstar's TriStar Controller check out www.morningstarcorp.com/tristar

To learn more about Morningstar's TriStar MPPT Controller check out www.morningstarcorp.com/products/tristar-mppt

