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Innovative Design of Light-Weight Finned Heat Sinks for Air Cooling of Electronics by Natural Convection

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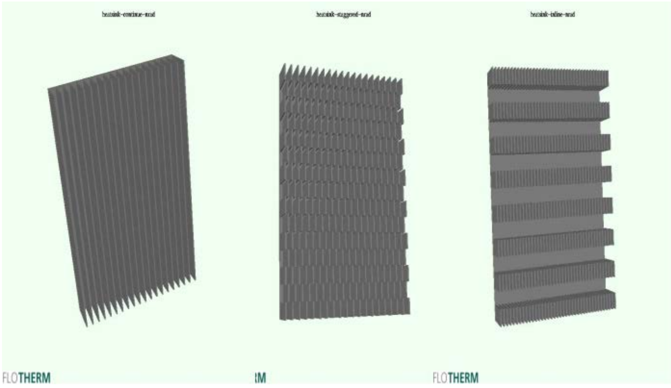
Abstract: For the tower or poled or even roof top mounted electronics, the heat sink weight is extremely important. This study describes the analysis and development of the light weight plain fin heat sink for cooling of electronics, especially for those outdoor wireless systems. A CFD analysis is performed to investigate the thermal performance of this finned heat sink at the vertical and horizontal positions under the passive cooling scheme, i.e. combined natural convection and radiation heat transfer. In addition, unlike most of previous work which is limited to either a uniform heating or uniform temperature at the base of the heat sink, the present investigation considers discrete heat sources with various power densities (heat loads) from electronics in contact with a section of the heat sink base. It should also be noted that all discussion, including the design, analysis and results can be applied to both the indoor and outdoor equipment. However, for any outdoor equipment, one must include the solar heating to the system into the design and analysis. It is found that the solar heating adds about 4 ºC to all parts of the system.

1. Introduction

Heat transfer by natural (or free) convection has long been considered as one of the most cost effective and reliable cooling methods. Natural convection with air has many practical engineering applications and is of special interest to the cooling of both indoor and outdoor electronic equipment. The advantages of air cooling by natural convection are simple, safe and cost effective.

For vertically straight- fin heat sinks, several experimental data (1-3) are available. Yeh et al. (5) performed a CFD analysis on the continuous finned heat sink and also on the staggered and in-line finned heat sinks as shown in Figure 1 at the constant wall temperature conditions. The results indicated that the continuous fins are most efficient thermally, and is followed by the staggered fins and then by the in-line fins. Though the in-line fin array has the greatest surface area, it has the least heat loss because of the smallest fin spacing choking the flow.



Continuous fins Staggered fins In-Line fins

Figure 1 Various Types of Finned Heat Sinks

Yeh (6) extended the analysis to examine the effects of the cover on the heat transfer. An unheated cover (shroud) is included in the CFD model where the heat sink base is at a constant temperature. To further understand the distance effect, the distance between the cover and the fin tips of the heat sink is varied from zero to 99”. The results also indicate that there will be no effect of the cover on the heat loss and entrant flow rate as long as the distance between the cover and the fin tips of the heat sink is greater than 4.36” with the fin height of 2.0”. Based on the limited data in this work, one may conclude that there is no effect of the cover on the heat transfer of a finned heat sink if the distance between the fin tips and the cover is greater than 2.5 times of the fin height.

For the tower or pole mounted equipment as shown in Figure 2, the weight of the heat sink is very important. The weight problem is further compound by a significant increase in the power density of the today devices which requires even larger heat sinks. The purpose of this work is to employ the knowledge gained from previous studies (5, 6) to the development of a light weight and high thermal efficiency heat sink for tower or pole mounted electronics.

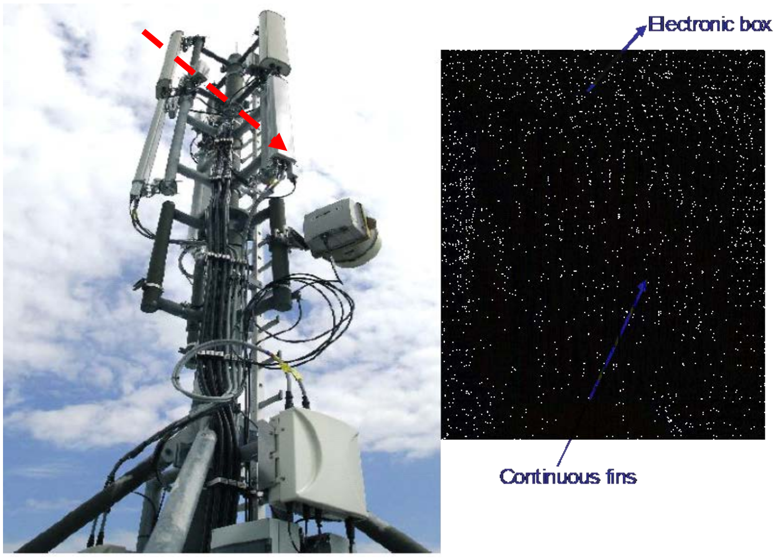


Figure 2 Tower Mounted Electronics

2. System Descriptions

The system under consideration includes a RF module with 3 power amplifiers mounted on its housing base plate. The RF module is then mechanically attached to a large heat sink. The cross section of the system and the thermal model are shown in Figure 3. The overall dimensions of the RF modules base plate are 220 mm x 100 mm x 6 mm. The size of three chips with various power densities (105W, 30W and 5W) is identical and its dimensions are 25 mm x 15 mm.

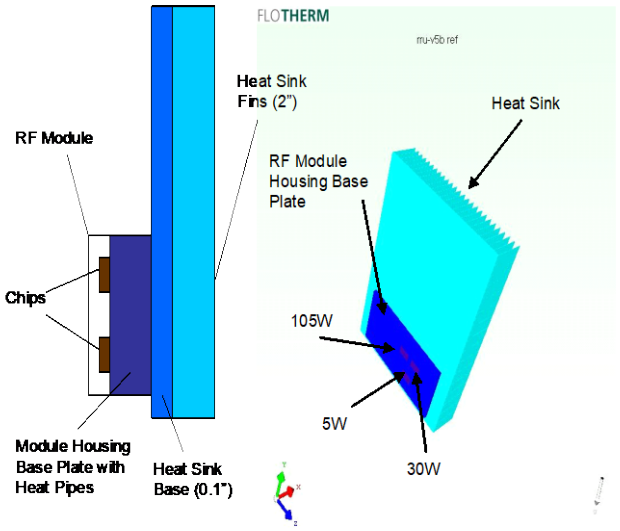


Figure 3 System Cross Section View and Its Thermal Model

3. Thermal Analysis

The heat sink with continuous straight plain fins is employed as illustrated in Figure 4 for this investigation. Figure 4 also includes all dimensions of the heat sink. Following the process described in the previous studies (5, 6), the fin spacing of the heat sink is optimized thermally. The total heat sink weight is 1.021 Kg (2.246 Lbm). The heat sink is made of AL 6061 with the thermal conductivity of 180 W/m-°C. In addition, unlike all previous studies (1-6) assuming the uniform base temperature of the heat sink, the present study includes several discrete heat sources on the module housing base plate which is mounted to a section of the heat sink.

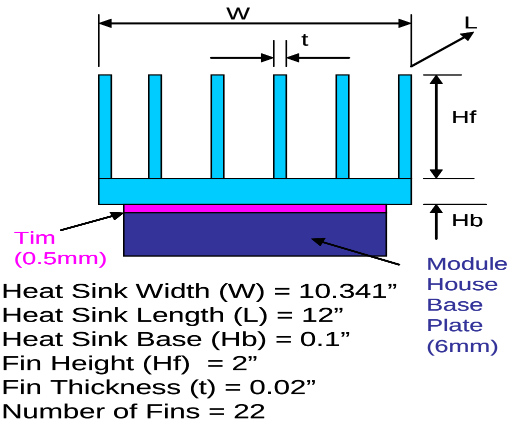


Figure 4 Heat Sink and its dimensions under Consideration

To improve the thermal spreading along 6 mm thick base plate which hosts all three components, the heat pipes are embedded on the base plate. With the embedded heat pipes, the equivalent planar thermal conductivities (Kxy) are estimated to be 1000 W/m - °C while the conductivity over the thickness (Kz) is assumed to be 180 W/m - °C. The ambient is assumed at 50 ºC and at the sea level.

The radiation heat transfer must always be included under the natural convection environments in all applications. This is especially true for the system operating at high altitudes where air density is small. To enhance the radiation heat transfer, the surface of the heat sink is coated with AZJ-4020 with emissivity of 0.9 and solar asbsorptivity of 0.15. The solar asbsorptivity is needed to compute the absorbed solar heating for any outdoor equipment.

4. Results and Discussion

For convenience, a commercial code, Flotherm, is used for the detailed CFD analysis. Two cases with equipment at the vertical and horizontal position are examined. The temperature/velocity profiles for the vertical and horizontal heat sinks are presented in Figures 5 and 6, respectively. Figures 5 and 6 give the surface temperature profile of the baseline heat sink at vertical and horizontal orientations, respectively. Because of non-uniform heating (various device power densities), the hottest section of the heat sink is located around the 105 watt chip location.

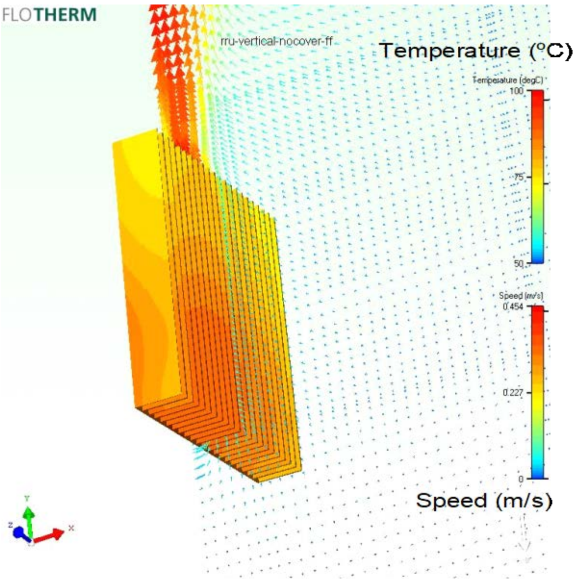


Figure 5 Velocity/Temperature Profiles for Vertical Heat Sink

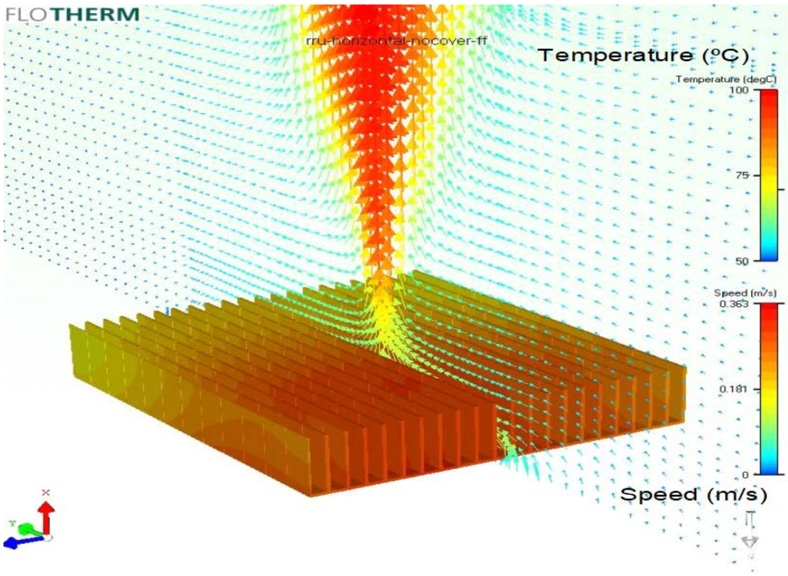


Figure 6 Velocity/Temperature Profiles for Horizontal Heat Sink

The flow patterns for the vertical and horizontal heat sinks are totally different. For a vertical heat sink, the flow enters not only from the bottom side but also from the front face (spaces between fins) of the heat sink. The latter is referred to as the entrained flow. However, the air flow enters the horizontal heat sink from both ends and follows the U-channels between fins. The hot air finally exits near the middle of the heat sink and flows upwards

The previous studies (5, 6) indicate that a cover to the heat sink will improve the thermal performance for a vertical heat sink. However, it will not work for a horizontal heat sink according to the flow pattern presented in Figure 9. Therefore, two aluminum covers are attached to the heat sink with the central section of the heat sink open for venting the hot air from a horizontal heat sink. Both small cover (3” x 10.341” x 0.1”) and large cover (4” x 10.341” x 0.1”0) are placed one inch from top and bottom sides of the heat sink to enhance the flow by enlarging the inlet/exit of individual U-channels. The temperature/velocity profiles are given in Figures 7 and 8, respectively for the vertical and horizontal heat sinks.

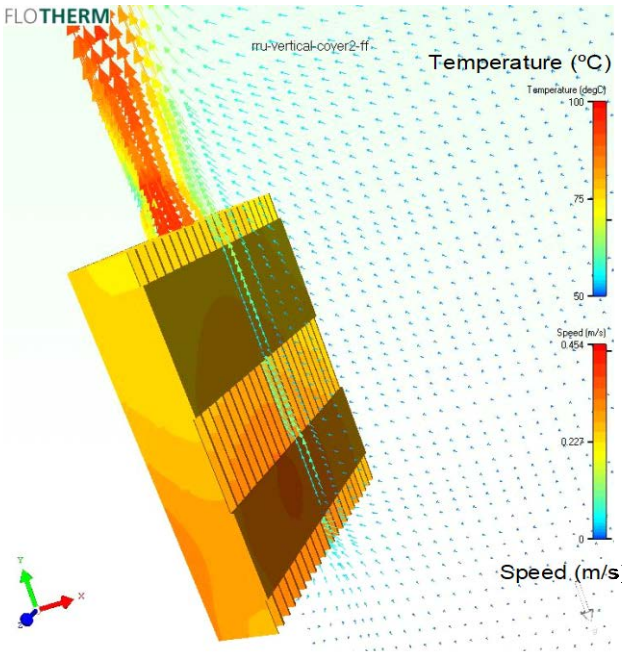


Figure 7 Velocity/Temperature Profiles for Vertical Heat Sink

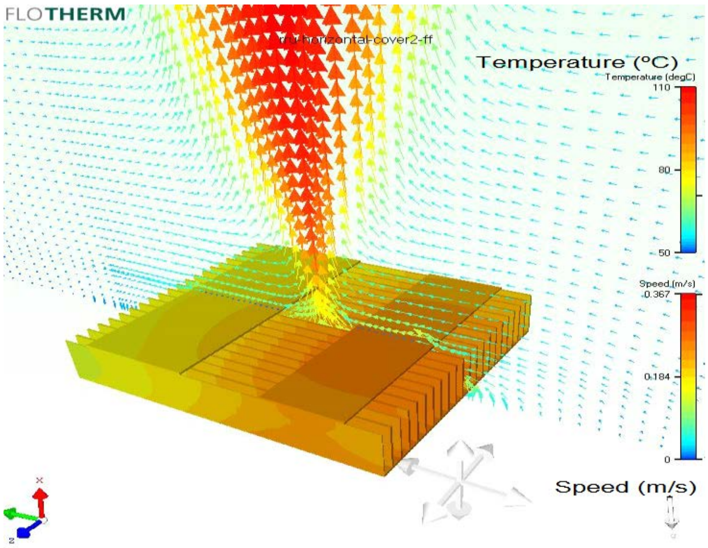


Figure 8 Velocity/Temperature Profiles for Horizontal Heat Sink

For the cases with/without the covers, the base plate temperatures under components are given Figure 9 for the heat sink at both vertical (VC, V) and horizontal (HC, H) positions. For the case without the cover (baseline), the maximum temperatures of the base plate are 96.5ºC and 99.9ºC for the vertical and horizontal heat sinks, respectively. For the case with cover, on the other hand, the maximum temperatures of the base plate are 94.9ºC and 100.2ºC for the vertical and horizontal heat sinks, respectively

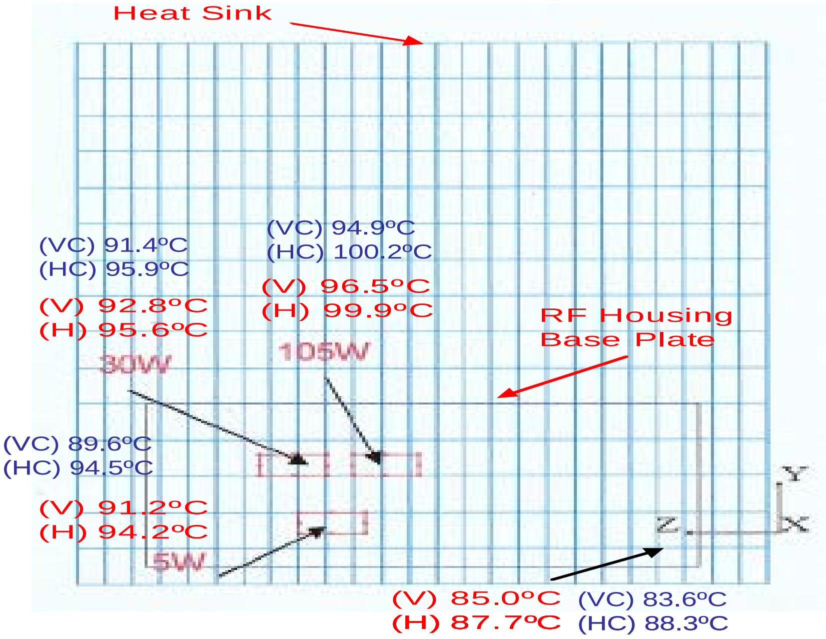


Figure 9 Temperature Distributions over Housing Base Plate with/without Covers

The summary results for all cases discussed above are presented in Table 1 It should be noted that the temperatures listed in the table are taken at 0.5 mm from the heated side of the base plate. As expected, the maximum temperature of the base plate occurs at the location of the 105W component. The results from Table 1 indicate that the vertical orientation is better than that of the horizontal position thermally. As should be expected, the covers do improve the thermal performance for the vertical heat sinks but have no practical impact on the horizontal heat sinks. The maximum temperature of the base plate in all cases has met the thermal limit of 110 °C (60 °C above the ambient). The total weights of the heat sink without and with the covers are 1.021 kg and 1.3427 kg, respectively. The ratios of system power to heat sink weight without and with the covers are 137.1 W/kg and 104.3 W/kg, respectively.

Table 1 Temperatures of Base Plate and Covers

	Without Cover (°C)		With Covers (°C)	
	Horizontal	Vertical	Horizontal	Vertical
105W	99.9	96.5	100.2	94.9
30W	95.6	92.8	95.9	91.4
5W	94.2	91.2	94.5	89.6
Right far End corner	87.7	85.0	88.3	83.6
Small Cover			90.2	85.1
Large Cover			78.6	77.5

It should also be noted that all above discussion, including the design, analysis and results can be applied to both the indoor and outdoor equipment. However, for any outdoor equipment, one must include the solar heating to the system into the design and analysis. The infrared (IR) energy emitted by the sun is at much shorter wavelengths than those emitted by a body near room temperature. This distinct characteristic allows for the use of some thermal control coatings that are very reflective in the solar spectrum but highly emissive to room temperature (long wavelength) IR. In other words, this method provides an opportunity using various coatings with high emissivity and low solar absorptivity for thermal control of outdoor equipment.

The NEB GR-487 which governs the mechanical and thermal designs of all outdoor telecommunications systems specifies the solar incident flux of 750 W/ m^2 should be applied to the project surface area of the heat sinks. Furthermore, the solar absorptivity of the external surface must include the aging effect and can be calculated by Equation (1)

$$\alpha f = (1 + 3 \times \alpha i) / 4 = (1 + 3 \times 0.15) / 4 = 0.36 \quad (1)$$

It is further assumed that the all solar heating is applied to the covers and the solar incident is determined as follows

$$qs = 750 \times 12 / 7 = 1285.7 \text{ W/m}^2 \quad (2)$$

The solar flux absorbed by the surface is determined by the following equation

$$qabs = 0.36 \times 1285.7 = 466 \text{ W/m}^2 \quad (3)$$

The temperature and velocity profiles of the vertical heat sink with the solar heating are presented in Figures 10. On the other hand, the temperature and velocity profiles of the horizontal heat sink with the solar heating are given in Figures 11. The summary results for the cases with and without solar heating are listed in Table 2. As can be seen from Table 2, the temperatures of the base plate and the cover are increased by about 4 °C due to the solar heating.

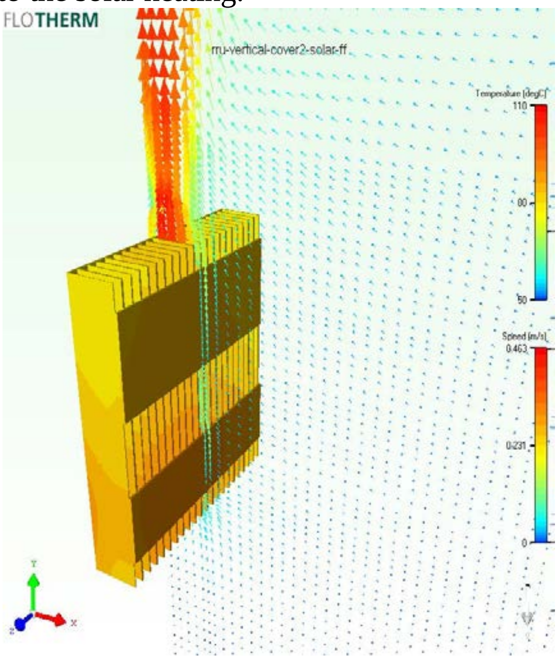


Figure 10 Velocity/Temperature Profile of Vertical Heat Sink with Solar Heating

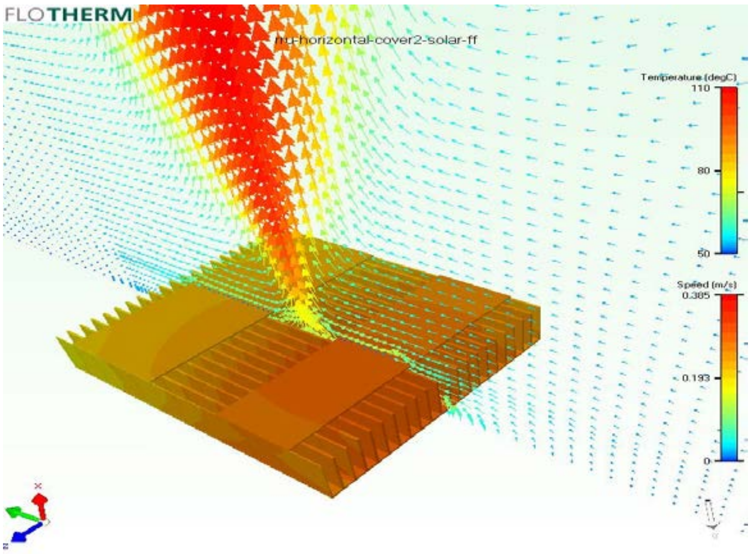


Figure 11 Velocity/Temperature Profile of Horizontal Heat Sink with Solar Heating

Table 2 Temperatures of Base Plate and Covers

	With Solar (°C)		Without Solar (°C)	
	Horizontal	Vertical	Horizontal	Vertical
105W	103.8	97.7	100.2	94.9
30W	99.5	94.1	95.9	91.4
5W	94.5	89.6	94.5	89.6
Right far End corner	91.9	86.4	88.3	83.6
Small Cover	94.2	88.2	90.2	85.1
Large Cover	82.8	81.2	78.6	77.5

5. Summary and Conclusion

The purpose of this work is to employ the knowledge gained from previous analyses (5, 6) to the development of a light weight and high thermal efficiency heat sink for air cooling of electronics. In addition, the radiation heat transfer that is omitted in all previous studies is included in the present analysis. Furthermore, the discrete heat sources with various power densities on the housing base plate in contact with the a section of the heat sink are considered in the present work as opposed to the common assumptions of uniform temperature (or heat flux) at the heat sink base in all previous work (1-6).

The results from Table 1 indicate that the vertical heat sink has a better thermal performance by about 3ºC over that of the horizontal one. For the case without the cover (baseline), the maximum temperatures of the base plate are 96.5ºC and 99.9ºC for the vertical and horizontal heat sinks, respectively. For the case with cover, on the other hand, the maximum temperatures of the base plate are 94.9ºC and 100.2ºC for the vertical and horizontal heat sinks, respectively.

The thermal performance of a horizontal heat sink with the cover will be greatly degraded if the full length cover is applied. This is due to the fact that the hot air will be trapped under the cover if the heat sink is fully covered. Therefore, the space of 3 " x 10.341" near the middle of the heat sink is open to vent the hot air for the horizontal heat sink. By doing so, the thermal performance of the vertical heat sink is slightly reduced while no noticeable effect on the maximum temperature between the cases with and without cover for the horizontal heat sink. The additional benefits from adding the covers are to strengthen the heat sink structures and to prevent the possible damages on the fin tips. Because the fin thickness is so thin that acts like razor blade. Therefore, the covers also provide an extra safety protection to personnel handing the heat sink.

In summary, the vertical orientation is better than that of the horizontal position thermally for both cases with or without covers. As should be expected, the covers do improve the thermal performance for the vertical heat sinks but have no practical impact on the horizontal heat sinks. The maximum temperature of the base plate in all cases with or without the covers has met the thermal limit of 110 °C (60 °C above the ambient temperature of 50ºC). The total weights of the heat sink without and with the covers are 1.021 kg and 1.3427 kg, respectively. The ratios of system power to heat sink weight without and with the covers are 137.1 W/kg and 104.3 W/kg, respectively. It should be noted that the fin space is thermally optimized for the case with the vertical heat sink. The optimal fin spacing may vary with the heat sink orientations.

It should also be noted that all above discussion, including the design, analysis and results can be applied to both the indoor and outdoor equipment. However, for any outdoor equipment, one must include the solar heating to the system into the design and analysis.

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