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A Comparative Study Of Heat Pipes And Thermosyphons For Passive Cooling of a High-Power LED Panel

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Abstract

High-power LED panels do generate heat that deteriorates their performance. The impact of heat on LED frequencies is also well documented. One practical way of dissipating heat is to incorporate active cooling systems that include fluid circulation around the panels. Various problems are encountered in active cooling when multiple LED panels are used for indoor plantation. Any malfunctioning in the system can cause damage to the LED panel. Passive techniques, on the other hand, have an advantage especially when two or more are simultaneously embedded in the system. Work at SJSU is using a commercial LED panel (100 W -white light with 200 W power) and provided fans are being replaced by a combination of heatsink and heat pipes. Experimental results clearly show a sharp reduction in the LED panel temperature (~ 25% reduction) alone with a heatsink. The surface temperature further reduced (~ 37%) as 12 heat pipes were integrated with the system. Next, the heat pipes were replaced with a total of 10 thermosyphons. The thermosyphons and heatsink were able to reduce the temperature by another 15 %. The heatsink integrated with the thermosyphons had an almost equivalent performance when compared to two fans that were used to cool the LEP panel surface. To further improve the performance of the passive cooling system an optimized heatsink for natural convection is being proposed that will be tested with the locally designed thermosyphons for this application.

Keywords: Heat Pipes, Thermosyphons, LED

1. Introduction

High-power light-emitting diode panels are in high demand due to their numerous industrial applications. These panels are required for efficient indoor agriculture. Indoor agriculture is gaining attention due to rapid growth in plants especially in the presence of UV lights. Space agriculture is another area that can benefit from efficient high -power LED panels. Other applications include water sterilization where strong UV light can eliminate bacteria. LEDs are semiconductor devices that produce light in visible, UV, and IR regions when an electrical current is passed through them. These emitting diodes are little, bright lights with great energy efficiency and durability. LEDs work uniquely in contrast to conventional lightings like incandescent or fluorescent light bulbs [1,2,3]. The LED technology also offers many other advantages over incandescent, neon, and minimal fluorescent lighting gadgets, for example, extraordinarily longer life expectancy (60,000 hours), lower usage of energy (90% more proficient), higher safety, and reduced maintenance cost [4]. High-power LED panels are now commercially available, but they still need design improvements. This is required because the thermal management of these systems is a great problem. Many active and passive techniques are employed to achieve an efficient way to keep the operating temperature of the LED panels at a workable level. Active techniques like cooling fans or circulating water are most favorable but problems do arise as the sudden breakdown of these cooling devices may cause great damage to the overall system. Passive techniques are usually favorable, but they are not very efficient when applied directly on an individual basis. For instance, most heat sinks solve thermal management problems for low-lumen LED lamps. An average heat sink alone will not cool a 75W- or 100W-equivalent lamp [5].

The current work is to explore the combination of two passive techniques that include mounting the LED panel on a heat sink along with heat pipes or thermosyphons. For this purpose, commercially available heat pipes were used whereas thermosyphons for this application were designed and developed here at IntelliScience location in San Jose. The main objective of the work is to compare the performance of heat pipes and thermosyphons in conjunction with the heat sink that was used to hold the LED – panel. It is important to note that this LED panel is supplied with two small fans that are being used to actively cooling the hot panel through forced convection. The main objective of the current work is to replace these two fans by a heat sink in which heat pipes or thermosyphons will also be mounted to manage thermal load in a completely passive manner.

The goal for this work is to reach cooling temperatures that fans are achieving at the panel surface without any active cooling. The following sections provide details on the experimental setup and related accessories along with the research methodology adopted in this work. Experimental results have also been added and discussed in greater detail.

2. Experimental Setup and Accessories

2.1. LED – Panel and Data Acquisition

For this project, the Vader LED Grow Light with UV/IR for indoor plants was selected, Figure 1. The specifications of the LED panel can be found in table 1. The panel operates at 200W and is dimensioned at 350 mm x 210 mm x 60 mm. The panel is cooled by means of two fans. Temperature measurements were made using k-type thermocouples. Keysight's Agilent Data Acquisition/Switch Unit (Model 34970A) is used for data acquisition and Keysight's Benchvue platform and Data Acquisition Control and Analysis application are being employed to extract data. A single card reader with 16 active channels of K type thermocouples is used for the DAQ. It was possible to store and retrieve the data from the DAQ to the EXCEL worksheet to plot and analyze it at a later stage.

Table 1. LED Panel Specifications

LED chip:	1000W
Power wattage:	200W
Input power:	AC100V-277V 50/60Hz
Spectrum:	380nm-840nm
Peak Wavelength	450nm, 660nm, 730nm
Peak Rate	450nm:660nm=1:8:0.3
PPFD:	500(umol/m^2/s)/13 inch (high) 385(umol/m^2/s)/16 inch (high) 150(umol/m^2/s)/24 inch (high)
Irradiation area:	A1=25X20inch/13inch (high) A2=32X24inch/16inch (high) A3=48X40inch/124inch (high)
Plant grow LED chip:	2835
Beam Angle:	120 degree
Gross weight:	3 kg
Product size:	350*210*60mm

Figure 1. LED Panel used for Thermal Management Investigation

2.2. Heat Sink Selection and Design

The heat sink selected for this LED panel has the same dimensions as those of the LED panel and has 31 rectangular but slightly tapered fins. This heat sink was commercially available, and its specifications are shown in Figure 2.

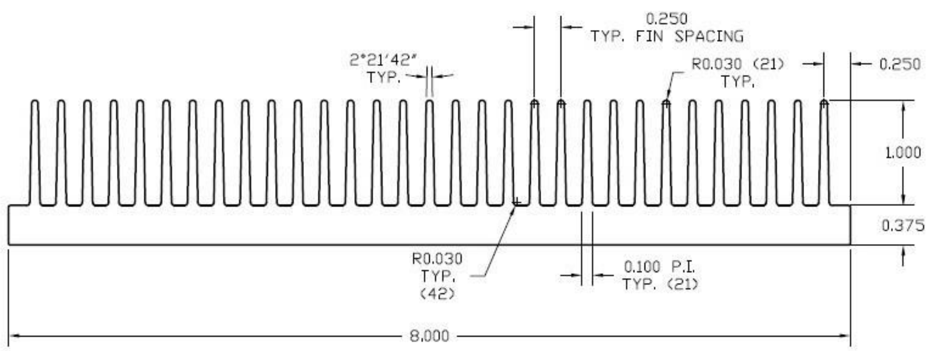

Figure 2. Heat sink specifications (in inches)

2.3 Heat Pipes and Thermosyphons Design

As mentioned earlier, both heat pipes and thermosyphons were mounted to perform passive cooling for the LED panel, it will be important to describe the basic working principles of both. As seen in Figure 3, there are three sections to a heat pipe. The evaporator section evaporates the working fluid, the condenser section condenses the working fluid, and the adiabatic section is the one in which heat does not enter or leave the system. For there to be a cycle of phase changes, there must be a force to bring the condensed liquid back to the evaporator section. For traditional heat pipes, wicks are utilized, and the capillary force brings the liquid to the evaporator to complete the cycle. In comparison, thermosyphons utilize gravity as the driving force to bring the condensed liquid back to the evaporator section. Therefore, the evaporator section must be below the condenser section for the thermosyphon to function properly. This isn't an issue for the design because there are options to mount both the heat pipe and thermosyphons vertically to take advantage of the gravitational force. In general, the simple design of thermosyphons allows them to be fabricated inexpensively compared to a more complicated and expensive wick. For the work commercially available heat pipes were employed whereas thermosyphons were designed and fabricated at IntelliScience Research Labs.

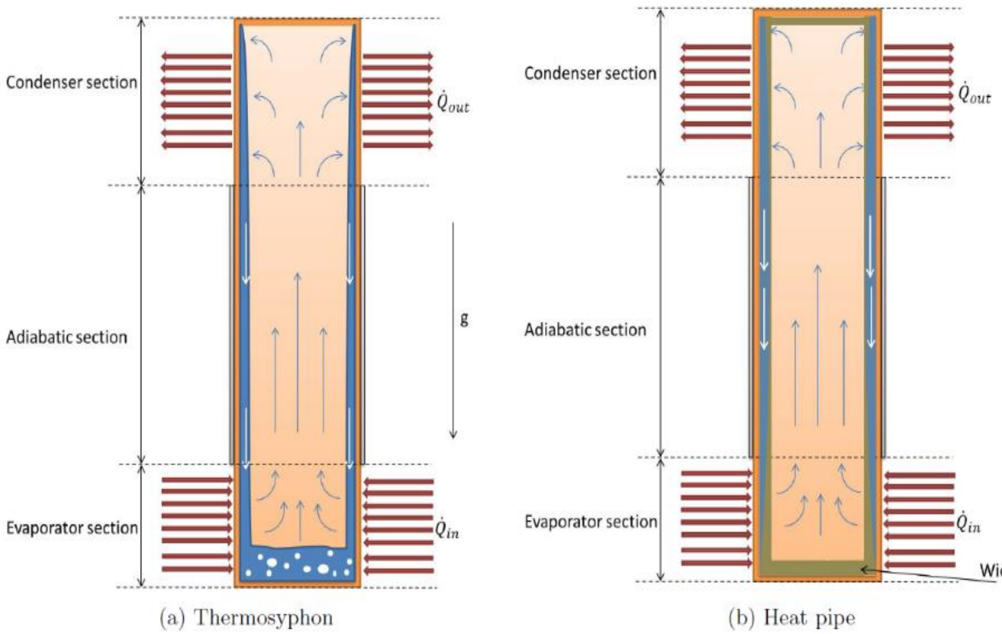

Figure 3. (a) Thermosyphon and (b) Heat Pipe: basic Design

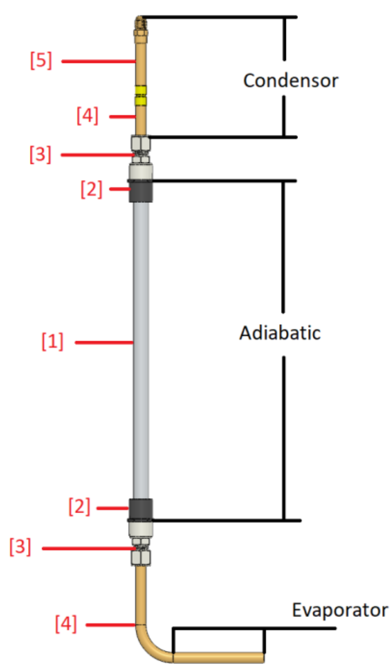

Figure 4. Thermosyphon Design

The thermosyphons were constructed with common refrigeration parts. The thermosyphons consisted of a few major components, the evaporator, the condenser, and the sight glass, Figure 4. The sight glass was a transparent section of the device where fluid activities were visible for visual observation.

All the material selected for the construction of the thermosyphon needed to be compatible with the working fluid. They needed to provide the necessary structural strength to withstand the internal working fluid pressure. They also needed to be chemically compatible where the working fluid was not going to corrode and deteriorate the structural components over time. The condenser and evaporator were made with material with good thermal conductivity to efficiently absorb and reject heat. Type K refrigeration copper tubing was selected to fabricate the evaporator and condenser. The evaporator consisted of a straight section of copper tubing and a copper end plug which were brazed together. The condenser consisted of a straight section of copper tubing and an access valve which were also brazed together. The sight glass section was made of schedule 80 transparent PVC tubing and fittings which were joined together using a solvent. Stainless steel mechanical fittings were used to assemble the condenser and evaporator onto the sight glass.

Working fluid was introduced into the thermosyphons after a series of pressure and vacuum tests. The assembled thermosyphons were pressurized with a blend of nitrogen and trace gas to the working fluid's operating pressure to ensure there were no leaks on the thermosyphons. An electronic leak detector was used to detect trace gas to locate leaks. After passing the pressure test, the thermosyphons were introduced to vacuum to evacuate all non-condensable gas before filling with working fluid. The thermosyphons were finally formed to shape after filling up with the working fluid.

2.4. Experimental Setup

In order to conduct an experiment and to measure temperatures at the back of the LED panel, the panel was mounted on a rectangular aluminum plate (backplate) that had several holes to insert thermocouples, heat pipes, and thermosyphons. Thermal paste was used between the LED panel and the backplate to avoid any air cavities and efficient heat conduction between two components. Figures 5 and 6 show the LED panel with mounted heat pipes and thermosyphons respectively. It is important to note that the LED panel for this experiment was mounted upside down the way it is expected to function in agricultural applications. This orientation was favorable for the heat pipes and thermosyphons to mount them vertically as shown in Figures 5 and 6.

K-type thermocouples were mounted on the back of the LED panel and were inserted in the aluminum backplate at several locations. Thermocouples were also mounted along the heat pipes and thermosyphons to monitor the temperatures to ensure the proper functioning of the device. The next section provides details on the experimental procedures and presents experimental results obtained from this study.

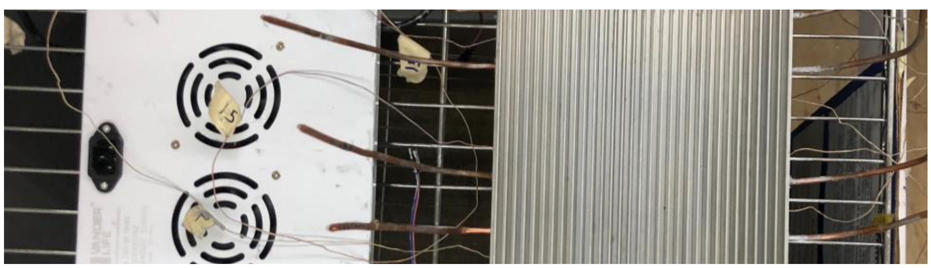

Figure 5. Heat Pipes mounted on the heat sink

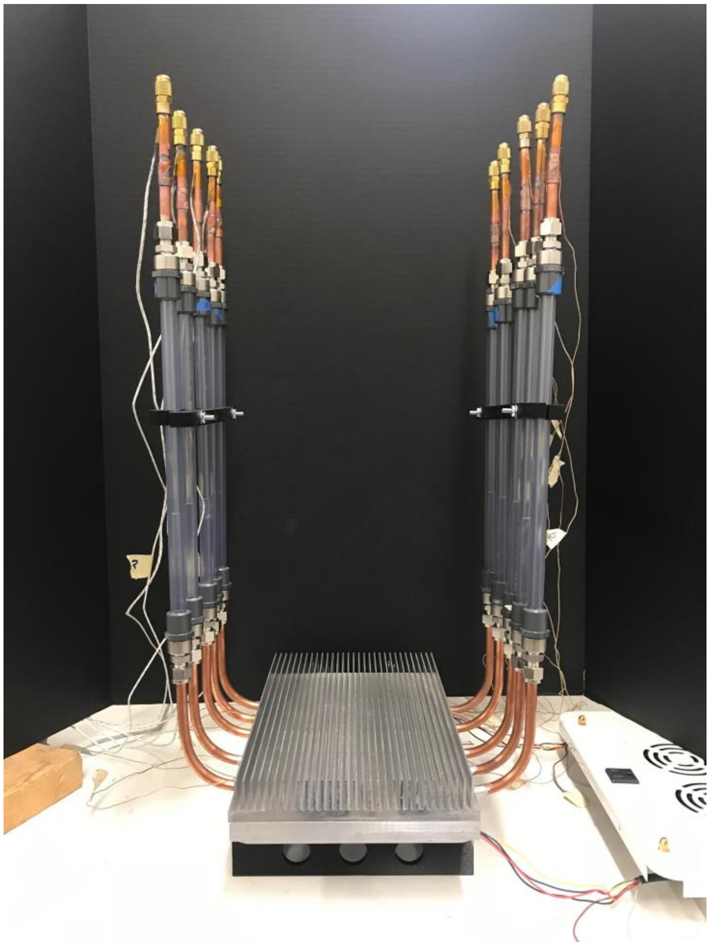

Figure 6. Thermosyphons mounted on the heatsink

3. Experimental Procedure and Results

The first step in this experiment was to measure the temperatures at the pack side of the LED panel as a function of time. Figure 7 shows the temperature variation and it seems that after an hour or so, the temperature at the backside of the LED panel reached its equilibrium value of around 120 degrees centigrade. Two fans were provided by the manufacturer of this panel and were turned on to see the impact of active cooling. Figure 7 shows that two fans were able to bring the temperature down to around 62 degrees centigrade showing about 48.3% reduction in temperature.

More experimental results were obtained by mounting heat pipes on the backplate. Temperature results are presented in Figure 7, which shows the combination of the heatsink and heat pipe was able to bring down the temperature to a lower value of about 76 degrees centigrade (~37 % reduction in base temperature). This value was further lowered when heat pipes were replaced by thermosyphons, as shown in Figure 7. Figure 7 clearly indicates that combining thermosyphons with heat sink can provide the required operating temperature for this LED panel i.e. temperature reached its equilibrium value of about 58 degrees centigrade (~ 52% reduction). This value is very close to the temperature that was obtained by using two fans showing the effectiveness of employing a combination of thermosyphons with the heat sink attached to the LED panel. During these experiments, a slight change in the environmental temperature was noted. To take into account this effect, delta T for each case was calculated and plotted in Figure 7. Figure 7 clearly shows that the performance of thermosyphons along with the heat sink is comparable to the fans that were originally used to cool down the LED panel.

4. Optimized Heat Sink Calculations

It was realized that optimizing the heat sink used in this study can enhance the thermal management process. To optimize the heatsink geometry, the optimization process described by Luo et.al.[6] was used. The optimization procedure allows the fin spacing, fin height, and fin thickness to be set as variable parameters. However, the derivation of heat-transfer theoretical calculations resulting from natural convection is heavily dependent on the geometry of the heatsink[7-10]. Therefore, the theoretical calculations must adapt to the changing geometry of the heatsink as the parameters are varied. For example, the Grashof number and Rayleigh number must be determined to calculate the Nusselt number. The Nusselt number can then be used to determine the heat transfer coefficient, which can ultimately determine the rate of heat transfer. However, the derivation of these calculations will change heavily depending on the geometry of the fins. Due to the wide variety of possible heatsink dimensions and, thus, the wide variety of required calculations, MatLab was used to perform the theoretical calculations. To meet the manufacturable limitations of the heatsink, only fin parameters were evaluated for fin thicknesses between 1 mm to 5 mm, fin spacings between 1 mm and 15 mm, and fin heights between 25 mm to 50 mm.

The optimization process outlined by Luo et.al.[6] is an iterative process. The iteration process begins by solving the heat transfer coefficient with a set of proposed fin parameters. The resulting heat transfer coefficient can then solve for the heat transfer of the heatsink. If the calculated heat transfer of heatsink is found to be less than the total heat generated by the LED system, that set of fin parameters will not meet the required design criteria. Thus, a new set of parameters is evaluated, and the process is repeated. As a result of the iteration process performed and calculated by MatLab, an array of heatsink dimensions were produced which would meet the design criteria. this array, a set of fin parameters using a fin height of 35 mm, fin spacing of 8.38 mm and fin thickness of 1.7 mm proves to be a possible set of heatsink dimensions that will meet the design criteria. Preliminary calculations show that by incorporating optimized heat sink along with thermosyphons can further reduce the operating temperature by another ten degrees. Optimized heat sink being proposed in this work is currently being tested and new results will be presented in the near future.

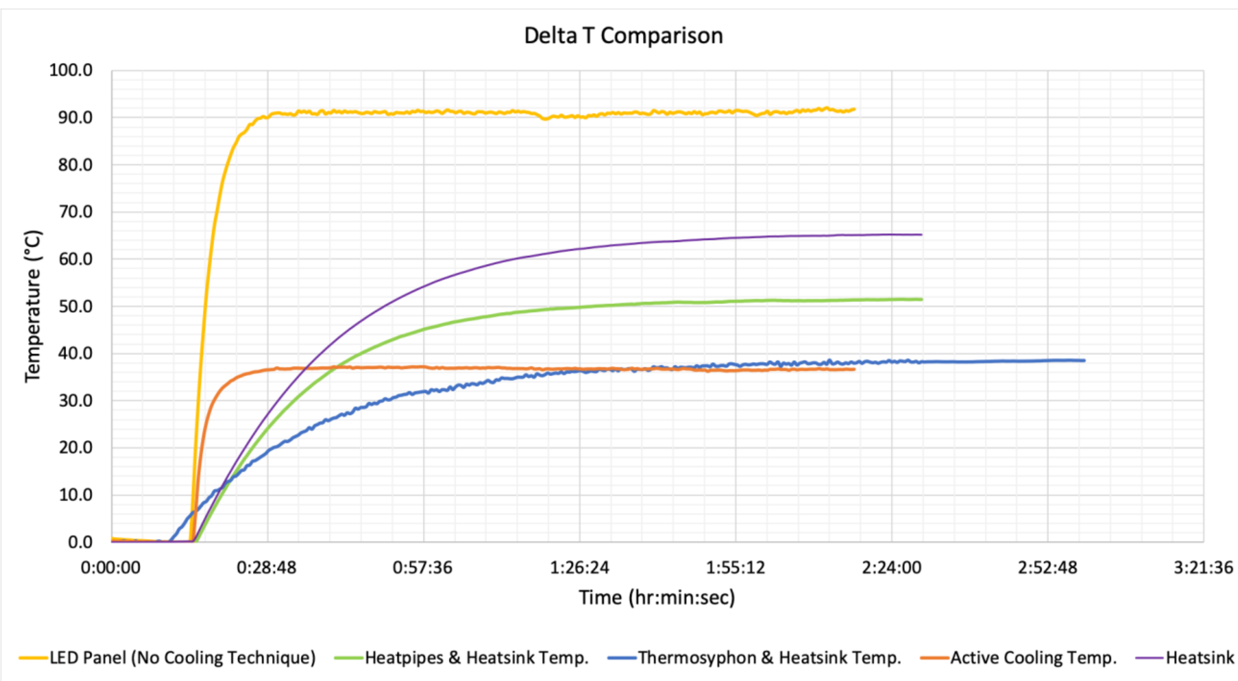

Figure 7. Comparison of delta T for all active and passive cooling setups

5. Conclusions

Passive cooling techniques were explored to replace the active cooling on a commercially available high-power LED panel. It was found that a combination of two passive techniques will enhance the thermal management process and will lead to the required operating temperature for the LED panel. For this purpose, both heat pipes and thermosyphons were used in conjunction with a heat sink. Thermosyphons, locally fabricated, gave better performance than the heat pipes. It was found that passive cooling method for this LED panel can be completely replaced by passive cooling techniques. The heat sink employed in this study was not optimized for its design. Preliminary calculations reveal that designing the optimized heat sink may lead to a further reduction in the operating temperature of the LED panel.

6. Acknowledgments

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7. References

1. Upadhyaya M.K., Zuk-Golaszewska K., Golaszewski J., The effect of UV-B radiation on plant growth and development, Plant Soil Environ., 49, 2003 (3), PP. 135-140
2. Learn About LED Bulbs. (n.d.). Retrieved December 02, 2016, from https://www.energystar.gov/products/lighting_fans/light_bulbs/learn_about_led_bulbs
3. Active Cooling Can Boost Lumen Output in LED Lighting. (n.d.). Retrieved December 03, 2016, from http://www.ledsmagazine.com/articles/print/volume-8/issue-6/features/active-cooling-can -boost-lumen-output-in-led-lighting-magazine.html
4. Why You Need an LED Heat Sink: Increasing Light Output & Extending Your LEDs Lifetime. (n.d.). Retrieved December 05, 2016, from http://www.ledsupply.com/blog/why-you-need-an-led-heat-sink/
5. Heat Pipes for Electronics Cooling Applications. (2016). Heat Pipes for Electronics Cooling Applications Electronics Cooling. Retrieved December 05, 2016, from https://www.electronicscooling.com/1996/09/heat-pipes-for-electronics-cooling-applicat ions/
6. Luo X., Xiong W., Chang T., Liu S., Design and Optimization of Horizontally-Located Plate Fin Heatsink for High Power LED Street Lamps, 59th IEEE Electronics components and technology Conference, May 26-29, 2009.
7. Dugan T., Ersepki J., Labat F., Datye A., Zaidi S.H., Heat Management of UV-LED Panels for Agriculture Applications, AIAA student research conference (Region VI), California Chapter, San Jose State University, San Jose, March 17-19, 2017.
8. J. Culham, M Yovanovich and Seri Lee (1995). Thermal Modeling of Isothermal Cuboids and Rectangular Heat Sinks Cooled by Natural Convection". IEEE Transactions on Components, Packaging, and Manufacturing Technology- part A. Vol. 19, NO 3. September 1995
9. Bilitzky, A. (1986). The Effect of Geometry on Heat Transfer by Free Convection from a Fin Array, M.S. thesis, Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel.
10. Van de Pol, D. W., and Tierney, J. K. (1973). Free Convection Nusselt Number for Vertical U- Shaped Channels, J. Heat Transfer, 87, 439