A Brief Review of Heat Sink, Heat Pipe, and Vapor Chamber as a Key Function of Thermal Solution for Electronic Devices

Mohamed Elnaggar, Mohammed Abu Hatab, and Ezzaldeen Edwan

***Abstract* — Electronics industry requires efficient design that can handle fast mathematical operations to compensate for the growing development and demand for processing power. These days, there are numerous equipment or parts inside machines called heating elements particularly with electrical or electronic devices and they should be cooled during the working process. However, with respect to their size, manufacturers are minifying day by day to satisfy requirements of users but the power should be maintained. Hence, elements withstand a high amount of heat and high heat flux (transition/mutability) is being generated during the working process. The main contribution of this study is to investigate thermal solutions using four cooling tools and to compare to each other and consider thermal design guidelines and factors as well. Furthermore, we review the appropriate thermal solutions for the produced heat from the electronic equipment and we present the effective and suitable tools which used to dissipate this heat. A heat sink, heat pipe, and vapor chamber are reviewed and compared depending on the previous studies that have implemented them.**

***Index Terms* — Thermal solution; Vapor chamber; Heat sink; Heat pipe; electronic devices.**

I. Introduction

There is no doubt that the heat generated by the electronic devices reduces the efficiency of the devices and may lead to hurting of these devices. Therefore, the heat is a big problem and must be dissipated in proper ways that lead to improving the efficiencies of these devices.

Because of the progress or development of the electronic devices, the heat generated by the processors inside them is in increase. Consequently, we have to use the appropriate tools to dissipate the generated heat and match the rapid technological development of these devices.

Many of the previous studies have reviewed these tools that get rid and dissipate heat. In [1] authors presented heat sinks, [2] reported thermosyphon, [3]-[6] described heat pipes, [7], [8] investigated heat sink with heat pipe, micro channel [9], and vapor chamber [10]-[12].

Most of the previous studies investigated one of the cooling tools for electronic devices individually and deepened in the description and carried out the mathematical and numerical analysis without addressing other cooling tools.

Based on that, the main contribution of this study is to review thermal solutions using, vapor chamber, heat sink and heat pipe and to compare to each other and consider thermal design guidelines and factors as well. Additionally, in this article, we will review the appropriate thermal solutions for the produced heat from the electronic equipment and will present the effective and suitable tools which used to dissipate the heat.

II. Thermal Management Solutions

The obvious truth in the electronics industry is that the increase of the temperature generated by processors is inversely proportional to the age and efficiency of the electronic devices. Consequently, it is worth describing cooling tools that sustain cooling techniques that dissipate the associated heat which it represents the main idea of the thermal solution. For thermal management solutions to be more effective, we must deal with system hardware solutions, system software solutions, and optimal thermal design [13].

III. Design Guidelines

Thermal design of the production of electronic devices is an important topic in research because thermal control solutions greatly affect the quality of the electronic product. Figure 1 shows the outline of the strategies for thermal design and its effect on electronic devices fabrication. In order to obtain a good thermal design solutions, all or most of the factors or effects which is found in Figure 1 must take into account.

Thermal design depends on understanding the concept of heat transfer and its branches such as conduction, convection and radiation.

In order to have a superb thermal design, we must proceed with the use of mathematics by analytical and numerical analyses, mathematical modeling, as well as verifying these methods by experiments.

Published on November 5, 2020.
Mohamed Elnaggar, Department of Engineering Professions department, Palestine Technical College – Deir El-Balah, Gaza Strip, Palestine.
(e-mail: melnaggar@ptcdb.edu.ps)
Mohammed Abu Hatab, Department of Engineering Professions department, Palestine Technical College – Deir El-Balah, Gaza Strip, Palestine.
Ezzaldeen Edwan, Department of Engineering Professions department, Palestine Technical College – Deir El-Balah, Gaza Strip, Palestine.

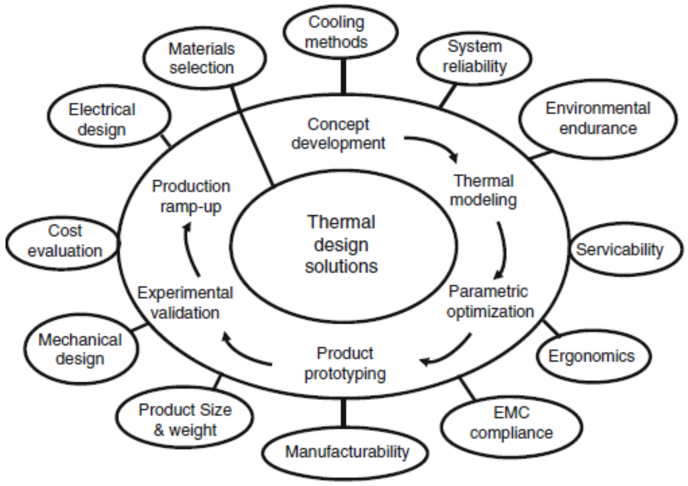


Fig. 1. The outline of the strategies for thermal design and its effect on electronic devices fabrication [13].

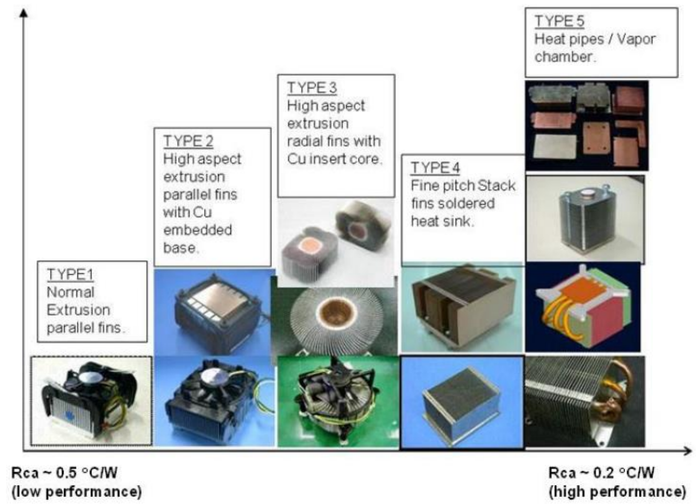


Fig. 2. Synopsis of cooling tools for desktop computers [14].

IV. Samples of Electronic Equipment Thermal Solution

The samples, which are reviewed in this study, are mainly subjected to the same idea, but different in terms of performance and use and we try to compare between them depending on the previous studies that have implemented them. The samples are heat sinks, heat pipes, and the vapor chamber.

A. Heat Sinks

The heat sink works as a heat exchanger that is used to transfer the heat generated by the electronic devices to the surrounding medium. The heat sink is usually placed on the processor to cool it by dissipating the heat generated from the processor to the surrounding medium. In order, the heat sink can dissipate the largest amount of the heat, it is designed with parallel fins of aluminum or copper to increase the surface area that disperses heat quickly and efficiently. In the case, a fan is used with the heat sink to dissipate the heat very quickly from the surfaces of the fins, active cooling is called, while the use of this sink without a fan, passive cooling is called.

The desktop personal computer is one of the most common electronic devices that use a heat sink for cooling Central Processing Units (CPU). Fig. 2 shows the history of the development of the heat sink which is used to cool desktop PC with related to the thermal resistance (R_{ca}). As it is known that the lower thermal resistance leads to increase the performance of the electronic devices. As shown in Fig. 1, the Type 1 of the heat sink has a high thermal resistance (R_{ca}) reach to 0.5 ^{0}C/W approximately which compared with Type 5 that consists from vapor chamber and heat pipe instead of heat sink which have high performance or lower thermal resistance which record 0.2 ^{0}C/W or less.

B. Heat Pipe

A high effective thermal conductivity is the core advantage of the heat pipe. The heat pipe consists of three main parts: 1) the evaporator which its task is the heat absorbing from the processor; 2) the adiabatic part, the temperature in this part is constant without change; 3) the condenser which expels the heat.

The internal components of the heat pipe are made up of the wall which is made usually from copper, the part that touches the inner wall is a wick, and the third component is the working fluid which is mostly distilled water.

As shown in Fig. 3, the operation principle of the heat pipe: the heat is absorbed by the evaporator leads to evaporate the working fluid, which is transferred to the condenser, where the fluid condenses and then returns to the evaporator again, due to the effect of the pressure drop between evaporator and condenser.

There are many types of the heat pipes such as cylindrical heat pipe, flat heat pipe, micro-heat pipe, and oscillating heat pipe.

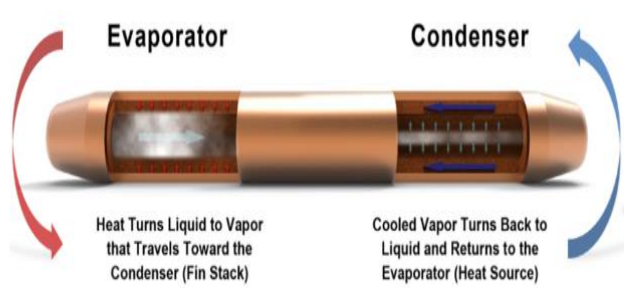


Fig. 3. Cylindrical heat pipe structure [15].

Although this type of heat pipe is widely used and developed, it still has some weaknesses. In order to enhance this system, a complicated structure (wick) is in need to take the working fluid back to the heating area. However, its performance may decrease because of the blending between condensed working fluid and evaporating vapor. Nevertheless, it is difficult to manufacture a fine product with this design.

C. Vapor Chamber

The vapor chamber has the same operating principle as the heat pipe. The heat pipe is a round pipe while the vapor chamber is a flat shape [14]. The comparison between the structure of the heat pipe and the vapor chamber is shown clearly in Fig. 4. The vapor chamber performance is better than the heat pipe because the vapor chamber is flat in shape, which causes the uniform heat distribution on the large surface that leads to dissipate heat more. In addition, the vapor chamber easier to connect to the processor because it is flat and also can add extra surfaces on it such as fins to dissipate heat the heat faster [14].

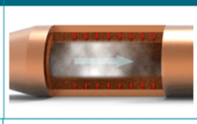
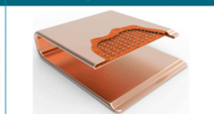
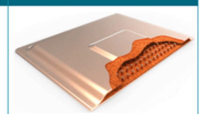
	Heat Pipe	Hybrid 1-Piece Vapor Chamber	Traditional 2-Piece Vapor Chamber
			
Initial Form Factor	Small diameter tube 3-10mm	Very large diameter tube 20-75mm	Upper and lower stamped plates
Shapes	Round, flattened and/or bent in any direction	Flattened rectangle, surface embossing & z-direction bendable	Complex shapes in x and y direction, surface embossing
Typical Dimensions	3-8mm diameter or flattened to 1.5-2.5mm. Length 500mm+	1.5-4mm thick, up to 100mm W by 400mm L	2.5-4mm thick, up to 100mm W by 400mm L
Mounting to Heat Source	Indirect contact though base plate unless flat & machined	Direct contact. Mounting pressure up to 90 PSI	Direct contact. Mounting pressure up to 90 PSI

Fig. 4. Comparison between the structure of the heat pipe and the vapor chamber [15], [16].

D. Heat Sink with Heat Pipe

Fig. 5 shows the heat sink with heat pipes for desktop computer cooling. It is noted that the increase in the number of the heat pipes in the heat sink leads to decrease the thermal resistance which increased efficiency that is due to the heat pipe has a very high thermal conductivity as compared to the copper rod. This type is used to cool the CPU of the desktop computer because of it has a large size and cannot be used in Laptops.

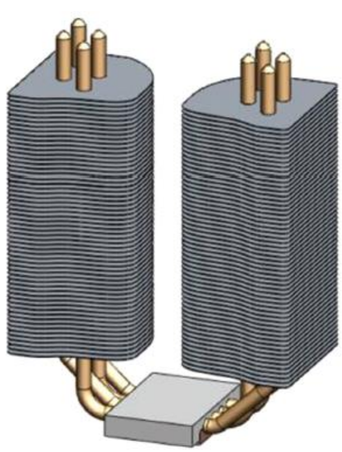


Fig. 5. Heat sink with heat pipes for desktop computer cooling [6], [8].

Fig. 6 shows the model that combines of three tools: the heat pipe, the heat sink, and the fan. The evaporator part of the heat pipe connects with the CPU and absorbs heat from the processor then transfers the heat to the edge of the electronic device and the heat sink is mounted on the end of the heat pipe (condenser part of the heat pipe) which the heat sink transfers heat from the heat pipe to the surrounding area outside the electronic device and fan is used to accelerate heat dissipation. This type is used for cooling the laptops as it also remote heat exchanger is called.

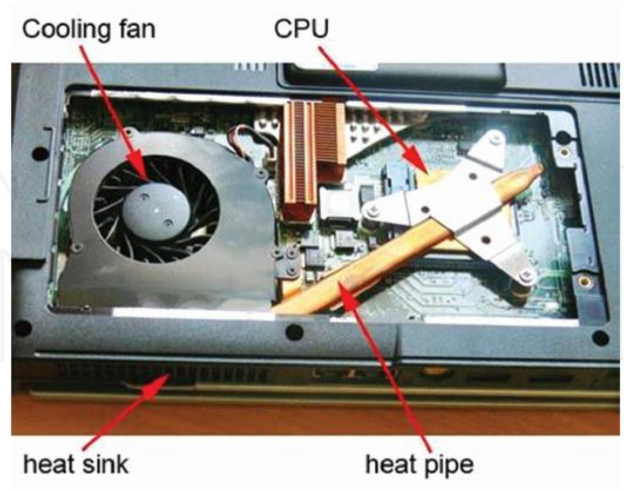


Fig. 6. Heat sink with fan and heat pipe for laptops cooling [6], [17].

V. Comparison between the Cooling Tools of Electronic Devices

Table 1 shows a comparison between the vapor chamber, the heat sink, the heat pipe, and the heat sink with the heat pipe in terms of thermal resistance, cost, and efficiency.

It is clear from Table 1 that the heat pipe and vapor chamber are highly efficient but they have a relatively high cost and this does not reduce the importance of the heat sink because it can be used extensively in desktop computers cooling and electronic devices of large size and it has low cost and easy to manufacture and installation and to be more efficient and reduce the thermal resistance it is combined with heat pipe.

TABLE I: Comparison between the Cooling Tools in Terms of Cost, Thermal Resistance, and Efficiency

Type	Cost	Thermal resistance	Efficiency
Heat sinks	Lowest	high	Low
Heat pipe	A little high	Low	high
Heat sink with heat pipe	High	Lower	Higher
Vapor chamber	Cost effective	Lowest	Highest

VI. Conclusion

A brief review of the appropriate thermal solutions for the produced heat from the electronic equipment and the effective and suitable tools which used to dissipate this heat are presented. Vapor chamber, heat sink and heat pipe are reviewed and compared between them depending on the previous studies that have implemented them. It has been shown from this quick review that the thermal solutions for the electronic devices are very important and must take into account many factors in the thermal design must be paid attention to the rapid development of electronic devices. The heat pipe and the vapor chamber proved to be more performance than the heat sink.

It is recommended to study thermal solution using the piezo fan in a detailed and precise manner, which is important in the development of technology.

The biggest challenge is how we can benefit from the dissipated heat from electronic devices to convert it into clean energy such as an electrical energy, which will use to charge these devices.

ACKNOWLEDGMENT

The authors are grateful to Islamic Development Bank for Post-Doctoral Research for supporting this research.

REFERENCES

[1] G. Ledezma and A. Bejan, "Heat sinks with sloped plate fins in natural and forced convection," *International Journal of Heat and Mass Transfer,* doi: 10.1016/0017-9310(95)00297-9 vol. 39, no. 9, pp. 1773-1783, 1996.
[2] G. Huminic, A. Huminic, I. Morjan, and F. Dumitrache, "Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles," *International Journal of Heat and Mass Transfer,* doi: 10.1016/j.ijheatmasstransfer.2010.09.005 vol. 54, no. 1-3, pp. 656-661, 2011.
[3] A. Faghri, *Heat Pipe Science and Technology*. Taylor & Francis Group, 1995.
[4] G. P. Peterson, *An Introduction to heat pipes: Modeling, Testing, and Applications*. New York: John Wiley & Sons, INC, 1994.
[5] P. D. Dunn and D. A. Reay, *Heat Pipes*, fourth ed. Oxford, UK: Pergamon Press, 1982.
[6] M. H. Elnaggar and E. Edwan, "Heat Pipes for Computer Cooling Applications," in *Electronics Cooling*: InTech, 2016.
[7] J. C. Wang, "Novel Thermal Resistance Network Analysis of Heat Sink with Embedded Heat Pipes," *Jordan Journal of Mechanical and Industrial Engineering,* vol. 2, no. 1, pp. 23-30, 2008.
[8] M. H. A. Elnaggar, M. Z. Abdullah, and M. Abdul Mujeebu, "Experimental analysis and FEM simulation of finned U-shape multi heat pipe for desktop PC cooling," *Energy Conversion and Management,* vol. 52, no. 8â€“9, pp. 2937-2944, 2011.
[9] A. A. Hussien, M. Z. Abdullah, and A.-N. Moh'd A, "Single-phase heat transfer enhancement in micro/minichannels using nanofluids: theory and applications," *Applied energy,* vol. 164, pp. 733-755, 2016.
[10] S.-C. Wong, K.-C. Hsieh, J.-D. Wu, and W.-L. Han, "A novel vapor chamber and its performance," *International Journal of Heat and Mass Transfer,* vol. 53, no. 11-12, pp. 2377-2384, 2010.
[11] S.-C. Wong, S.-F. Huang, and K.-C. Hsieh, "Performance tests on a novel vapor chamber," *Applied Thermal Engineering,* vol. 31, no. 10, pp. 1757-1762, 2011.
[12] Y.-T. Chen, S.-W. Kang, Y.-H. Hung, C.-H. Huang, and K.-C. Chien, "Feasibility study of an aluminum vapor chamber with radial grooved and sintered powders wick structures," *Applied Thermal Engineering,* vol. 51, no. 1-2, pp. 864-870, 2013.
[13] X. C. Tong, *Advanced materials for thermal management of electronic packaging*. Springer Science & Business Media, 2011.
[14] M. Mochizuki, T. Nguyen, K. Mashiko, Y. Saito, T. Nguyen, and V. Wuttijumnong, "A Review of Heat Pipe Application Including New Opportunities," *Frontiers in Heat Pipes,* vol. 2, no. 1, pp. 1-15, 2011.
[15] B. C. *Heat Pipes and Vapor Chambers – What's the Difference?* Available: https://celsiainc.com/blog-heat-pipes-and-vapor-chambers-whats-the-difference/.
[16] G. Meyer. (2017). *What's the Difference Between Heat Pipes and Vapor Chambers* Available: http://www.electronicdesign.com/components/what-s-difference-between-heat-pipes-and-vapor-chambers.
[17] W. G. (2011). *Why eTray laptop trays don't have fans*. Available: http://www.etray.co.uk/etraynews/index.php/why-etrays-dont-have-fans]/.

Dr. Mohamed Elnaggar is an assistant Professor of engineering at Palestine Technical College. His research interests include solar cooling, thermal management, fluid mechanics, heat transfer, Renewable energy and heat pipes. He received the B.Sc. degree in mechanical engineering from Istanbul Technical University, Istanbul, Turkey, the M.Sc. degree from Marmara University, Istanbul, and the Ph.D. degree from the Universiti Sains Malaysia, Malaysia. He has published about 25 scientific papers and book chapter in reputed international journals and conferences.

Mohammed S. R. Abu Hatab received the B.S. degree in Electrical Engineering from Middle East Technical University, Ankara, Turkey in 1999, and his M.S. degree in Electrical Engineering from Islamic University, Gaza, Palestine in 2008. He is currently the Vice Dean for Academic Affairs and a lecturer in the Engineering Department at Palestine Technical College, Deir El-Balah, Palestine. He was the head of continuing education department in 2001-2006. He held the position of head of the Department of Engineering in 2011-2016. He is an IEEE member since 1999. His research interests focus on control systems, process control, embedded system, electronic devices and renewable energy. conducted several national workshops. He was a recipient of the UNRWA scholarship during B.S. study, He was a recipient of the best thesis award in the Islamic university 2009. He was Deputy Chair and Head of Organizing Committee of the international conference on Promising Electronic technologies. He has an experience in the academic field lecturing for electrical and computer engineering courses.

Dr. Ezzaldeen Edwan is an assistant professor and head of scientific research department at Palestine Technical College. He received the B.Sc. degree in electrical engineering from Birzeit University, Palestine in 1997 and the M.Sc. degree in electrical engineering from Oklahoma State University, OK, USA in 2003 and the doctoral degree in electrical engineering in 2013 from the University of Siegen, Germany. His main research interests are sensors, inertial navigation systems, control systems, mobile robotics, sensor fusion and applied estimation theory. He has an experience in the academic field lecturing for electrical and computer engineering courses and in research through participating in different European research projects. He is a recipient of the Fulbright and the DAAD scholarships, respectively. He authored and coauthored more than 40 scientific papers in well-known journals and international conferences. Moreover, he participated in several European Erasmus+ projects as a coordinating partner e.g. MS@CPS and EDU4ALL projects. He is the founder of the IEEE International Conference on Promising Electronic Technologies Conference (ICPET) from 2017 - 2019.