DESIGN AND SIMULATION OF THERMAL MANAGEMENT SYSTEM OF SERVERS USING PHASE CHANGING MATERIAL

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Abstract

Today, data centers occupy a very large place in daily lives. In this period when the information age comes, data centers are of great importance both for the work on the computer and for people to reach each other. People are now more dependent on computers and the internet than ever before to continue their daily lives.

It is critically important that the server systems continue to operate. Since communicating with each other 24/7 over the web has become fundamental , the servers need to be cooled continuosly also. However, in some emergency and disaster situations, these cooling systems may stop working or malfunctions may occur. Disasters such as fire and earthquake may damage the cooling systems of the server rooms, or there may be sudden overloads to the web servers by the users that means rapid fluctuations in the server cabinet temperature. At this point, *Phase Change Materials* can help servers run until cooling systems start. Phase Change Materials, abbreviated as PCM, absorb the temperature of the environment and at certain degrees they release absorbed heat. This ensures that the PCM can be used repeatedly for cycles. By taking advantage of the heat storage feature of PCM, we can ensure that the server cabinet temperature rises gradually, allowing the server to continue its operation. With paraffin wax-based PCM, which can be produced at very low prices, it can both reduce the potential interruptions that may occur in the servers at critical times and reduce the cooling system expenses.

Bu günlerde veri merkezleri günlük hayatta oldukça yer almakta. Bilgi çağına ulaşılan şu dönemde gerek bilgisayar üzerinden yapılan işlerde, gerekse insanların birbirine ulaşması için veri merkezleri çok büyük önem arz etmekte. Bireyler günlük yaşantıya devam etmek için artık bilgisayarlara ve internete hiç olmadığı kadar bağlı . Server sistemlerinin operasyonlarına devam etmesi kritik derecede önemli. Web üzerinden 7/24 iletişim kurulduğu için kesintisiz bir şekilde serverların soğutulması gerekiyor. Ancak bazı acil ve afet durumlarında bu soğutma sistemlerinin çalışması durabilir veya arızalar çıkabilir. Yangın, deprem gibi afetler server odalarının soğutma sistemlerine zarar verebilir, veya web serverlara ani olarak kullanıcılar tarafından aşırı yüklenmeler olabilir ve server kabin içi sıcaklığında hızlı dalgalanmalar olabilir. İşte bu noktada, Faz Değiştiren Malzemeler soğutma sistemlerinin devreye girmesine kadar serverların çalışmasını yardımcı olabilir. FDM olarak kısaltılan Faz Değiştiren Malzemeler, belli derecelerde absorbe ettiği ısıyı dışarıya vermektedir. Bu da FDM'nin tekrar tekrar kullanılabilmesini sağlar. FDM'nin ısı soğurma özelliğinden yararlanarak server kabin içi sıcaklığının kademe kademe yükselmesini sağlayarak server'ın operasyonuna devam etmesi sağlanabilir. Oldukça ucuz fiyatlara imal edilebilecek parafin mumu bazlı FDM ile hem önemli zamanlarda serverlarda oluşabilecek potansiyel kesintiler azaltılabilir hem de soğutma sistemi maliyetleri düşürülebilir.

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Symbols

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T	Temperature, ˚C	1
V	Volume, m^3	2
C_p	Specific heat capacity, [kJ/(kg.K)]	2
h_f	Heat storage capacity, [kJ/kg]	2
k	Thermal conductivity, [kJ/(m.K)]	2
h	Heat conductivity,[W/(m.K)]	2
M	Mass, kg	2
L	length, m	6
Q	Heat, J	2
ρ	density, kg/m^3	6
T	Time, sec	6

Abbreviations

PCM : Phase Change Material
PW : Paraffin-Wax
RH : Relative Humidity
ASHRAE : American Society of Heating, Refrigerating

Introduction

1.1 Purpose and Scope of the Study

In today's world everything becomes more data centered. According to that, Servers are getting more important than ever. In almost every situation technology is preferred against waiting long times or wasting money- *Private computers, mobile phones, modems, electronic defense systems and other communication devices*- Human beings need to advance in every possible way but there are always some problems that need to be dealt with. Increasing the amount of data means more data processing-computing energy. Therefore, there is a huge amount of power supply that these machines need. Regarding that, servers need to be cooled in dangerous ranges of temperatures in case of getting to high levels of temperature increasing.

1.2 Method of Study

Paraffin based material such as Paraffin Wax (PW) -also called as Phase Change Material (PCM)- is highly recommended because of heat absorbing and releasing features and heat storage capacities. Air cooling is another method which is very popular in these sectors but it is high cost to businesses and also less efficient according to PCM cooling. In the project, it is referred to cool down the server cabinets instead of the servers' transistors which is more in the search area of Information technologies. Solid paraffin is preferred instead of liquid since at first the server cabinets will be coated with plates.

Figure 1. Principle of Phase Change Material

PCM materials have high heat storage capacity and heat storage-release features at nearly constant temperatures. Also they have a long life-time, especially the customers who utilize the material onto the server cabinets will need this feature. In the long run, material will go through several thousands of cycles with almost the same performance. Paraffin-wax material has a melting temperature range between approximately -10 °C and 90 °C. It is easy to handle and non toxic for those who will utilize it with bare hands. This feature also helps the maintenance team for routine care.

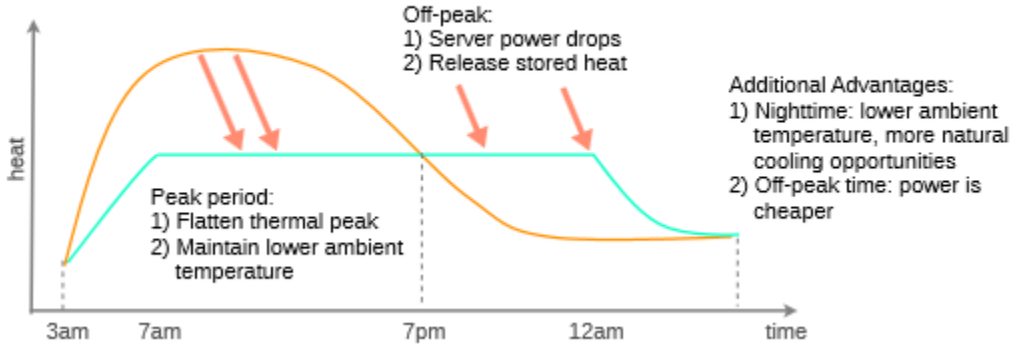

Figure 2. Thermal time shifting using PCM[1]

1.3 Constraints of the Study

Melting and congealing [°C] areas of PW are very important for a robust design of thermal management system. Also heat of fusion [kJ/kg] , specific heat capacity [kJ/kg.K] ,density of solid and liquid [kg/m³] , heat conductivity [W/(m.K)] , volume expansion [%] and maximum operating temperature [°C] are the limits that need to be thought when choosing the right material. These parameters will be checked out throughout the study.

[1] M. Skach, *et al*.,"Thermal Time Shifting: Decreasing Data Center Cooling Costs with Phase-Change Materials" in *IEEE Internet Computing*, vol. 21, no. 04, pp. 34-43, 2017; doi: 10.1109/MIC.2017.2911418

Property or Characteristic	Paraffin Wax	Non-Paraffin Organics	Hydrated Salts	Metallics
Heat of Fusion	High	High	High	Med.
Thermal Conductivity	Very Low	Low	High	Very High
Melt Temperature (°C)	-20 to 100+	5 to 120+	0 to 100+	150 to 800+
Latent Heat (kJ/kg)	200 to 280	90 to 250	60 to 300	25 to 100
Corrosive	Non-Corrosive	Mildly Corrosive	Corrosive	Varies
Economics	$$	$$$ to $$$$	$	$$ to $$$
Thermal Cycling	Stable	Elevated Temperature Can Cause Decomposition	Unstable over Repeated Cycles	Stable
Weight	Medium	Medium	Light	Heavy

Table 1. PCM Types Include Paraffin Waxes, Non-Paraffin Organics, Hydrated Salts, and Metallics.

Literature Review

Phase change materials have been used in various ways in the literature. Due to the ever-increasing technological need, there are various studies on the search for new PCMs. Apart from these research studies, the practical use of PCMs is also being developed. It has been observed that the potential uses of PCM are very diverse. It is possible to apply heat storage to many sectors. To give a few examples;

-In the construction sector: keeping the temperature constant in the buildings,
-In the medical field: blood, drug, organ transport,
-In the textile industry: Designing useful clothes suitable for hot and cold climates,
-In the HVAC area: System cooling

In the literature research, studies on cooling the servers were examined. Generally, the main purpose of these studies is to reduce the costs of server cooling systems. According to the results of the studies, it is possible to reduce the cooling cost in the servers by using paraffin wax. In these studies, PCM was not applied to server cabinets, but to electronic components that generate heat directly within the server. In this way, it is aimed to achieve maximum efficiency with PCM.

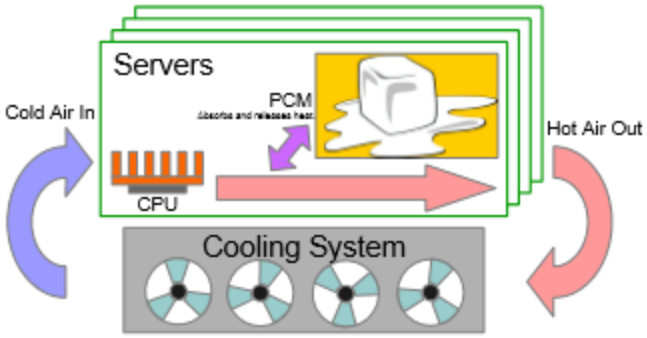

Figure 3. Integrating PCM in Warehouse-Scale Computers[2]

To prevent high server failure, the cooling system must be able to handle the peak demand of the data centre. Further, the cooling system also may become insufficient as servers undergo upgradation or replacement.[3] Instead of the traditional cooling system where the cooling system is not sufficient, the PCM can manage the cooling server, though for a short period of time.

Theoretical Procedure

If an emergency scenario situation is required and depending on this emergency, the server temperature and server room temperature values will need to change. As an example scenario, a situation that increases the workload of the server is required. As the request density to the server increases, the processor and other electronic components of the server begin to generate heat.
In order for the server to continue its operation in the face of this suddenly developing emergency, the air conditioning of the cabinet must be done very well. PCMs can be used to prevent spikes in temperatures. Uninterrupted operation of the server can be ensured by taking advantage of PCMs thermal energy storage feature.

Table 1 shows the system room temperature and humidity values recommended by the American Society of Heating, Refrigerating (ASHRAE).

[2] M. Skach, *et al*.,"Thermal Time Shifting: Decreasing Data Center Cooling Costs with Phase-Change Materials" in *IEEE Internet Computing*, vol. 21, no. 04, pp. 34-43, 2017; doi: 10.1109/MIC.2017.2911418

[3] In Ismaël, . W., & Nova Science Publishers,. (2020). *Phase change materials: Technology and applications*., Page: 58

	2004 publication	2008 publication
Temperature Lower Limit	20 °C	18 °C
Temperature Upper Limit	25 °C	27 °C
Humidity Lower Limit	40 % Relative Humidity (RH)	5.5 Dew Point
Humidity Upper Limit	55 % Relative Humidity (RH)	60 % RH and 15°C Dew Point

Table 2. Recommended System Room Temperature and Humidity Values

Based on the values suggested by ASHRAE in 2008 in Table 1, the ideal system room temperature should be between 18-27°C. However, the ambient temperature should not be higher than the values recommended by the server manufacturers.
In Table 2, the maximum and minimum ambient temperature values are explained in the user manuals of two important computer manufacturers DELL and IBM.

Server Name	**Temperature**
Dell PowerEdge R740	10°C- 35°C (50°F- 95°F) with no direct sunlight on the equipment.
IBM 8348-21C	10°C - 35°C (50°F - 95°F)

Table 3. Environmental temperature for continuous operation for Servers

With given values in Table 2, the temperature inside the cabinet where the server is located can go up to 35°C. Although this value is not a recommended value, the maximum temperature can go up to 40°C in various sources. According to ASHRAE, the ideal temperature should be up to 27°C. According to the emergency scenario, the maximum interior temperature can be accepted as 27-35°C, taking this information into account. The melting point of the PCM to be used should also start from 27°C. Due to the thermal storage feature of the PCM, the server cabinet temperature will start from 27°C and gradually increase to 35°C.

Data Results and Recommendations

Based on the recommended ambient temperature values published by ASHRAE and server manufacturers, it is possible to cool the server in emergency and disaster situations with PCM. This cooling process can be done with commercial paraffin wax. There are commercial organic PCM of German origin Rubitherm company in the market with various features. For example, Rubitherm's commercial paraffin wax coded RT35 has ideal melting and freezing points to use when its properties are examined.

The most important data:	Typical Values	
Melting area	29-36 main peak: 33	[°C]
Congealing area	36-31 main peak: 35	[°C]
Heat storage capacity ± 7,5%	160	[kJ/kg]*
Combination of latent and sensible heat in a temperatur range of 26°C to 41°C.	45	[Wh/kg]*
Specific heat capacity	2	[kJ/kg·K]
Density solid at 15°C	0,86	[kg/l]
Density liquid at 45°C	0,77	[kg/l]
Heat conductivity (both phases)	0,2	[W/(m·K)]
Volume expansion	12,5	[%]
Flash point	167	[°C]
Max. operation temperature	65	[°C]

Table 4. Specifications of Rubitherm RT35[4]

This material can be used by taking advantage of the cheapness of paraffin wax. Many academic studies reveal that the PCM's direct contact with the server's processor is the most efficient method for server cooling. However, this subject contains very technical details and it is necessary to make a separate PCM application for each server brand. Instead, it can be applied to cover the inner surfaces of the server cabinets with PCM plates. This method is both cheaper and faster.

[4] Rubitherm RT35, https://www.rubitherm.eu/media/products/datasheets/Techdata_-RT35_EN_09102020.PDF

Conclusion

As mentioned previously, cooling the server cabinets with Phase Change Material -*Paraffin Wax*- is more efficient and due to its heat storage capacity, data centers' cabinet temperature can decrease by absorbing the heat and increase by releasing when the temperature range of Servers cabinets are in mean values. This study shows the main reason why we need to cool down the temperature of servers' cabinets, which material to select, how and where to place the PCM, past studies and research that is useful.

References

1 M. Skach, *et al*.,"Thermal Time Shifting: Decreasing Data Center Cooling Costs with Phase-Change Materials" in *IEEE Internet Computing*, vol. 21, no. 04, pp. 34-43, 2017; doi: 10.1109/MIC.2017.2911418

2 M. Skach, *et al*.,"Thermal Time Shifting: Decreasing Data Center Cooling Costs with Phase-Change Materials" in *IEEE Internet Computing*, vol. 21, no. 04, pp. 34-43, 2017; doi: 10.1109/MIC.2017.2911418

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4 Rubitherm RT35, https://www.rubitherm.eu/media/products/datasheets/Techdata_-RT35_EN_09102020.PDF

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