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

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Research Project Thesis

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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

T	Temperature, °C
V	Volume,
C_p	Specific heat capacity, [kJ/(kg.K)]
hf	Heat storage capacity, [kJ/kg]
k	Thermal conductivity, [kJ/(m.K)]
h	Heat conductivity,[W/(m.K)]
M	Mass, kg
L	length, m
Q	Heat, J
$\dot{Q}$	Heat flow rate
HC	Heat Transfer Coefficient
Thot	Hot temperature
TCold	Cold temperature
A	Area of surface
ρ	density, kg/
T	Time, sec
σ	Stefan Boltzmann Constant

Abbreviations

PCM : Phase Change Material

PW : Paraffin-Wax

RH : Relative Humidity

ASHRAE : American Society of Heating, Refrigerating

TES : Thermal Energy Storage

TTS : Thermal Time Shifting

VMT : Virtual Melting Temperature

CPU : Central Processing Unit

GPU : Graphics Processing Unit

RAM : Random Access Memory

LED : Light Emitting Diodes

EIA : Electronic Industries Association

Introduction

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.

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.[2] 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 PCM capsules.

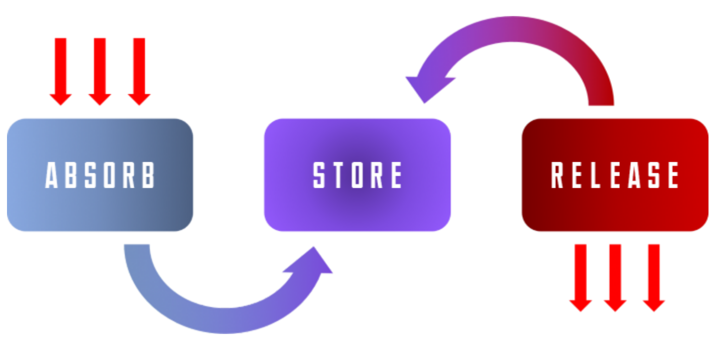


Figure 1. Principle of Phase Change Material

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.

Constraints of 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/m^3], 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.
It is necessary to use paraffin wax with a low melting temperature for this study.

Servers

History of the Servers

Servers are computer components on a network that handle requests sent by clients. This name was first used in 1953 by British mathematician David George Kendall in his work on queuing theory. In earlier periods, the server name was used in different ways in the telecommunication sector. The US Department of Defense used it to identify hosts in the ARPANET network which it created for internal communication purposes. Later, the use of the word became widespread over time.
To understand the working logic of servers, it is necessary to understand the client-server model. The main purpose of this model is to make the best use of computational resources globally. The duty of servers is to store and protect data. It also has the duty of processing requests from clients.

Server Types

Servers are produced in various types according to their intended use. They are special computers, each with various functions. They are produced according to their usage areas for maximum performance.[3]

- Web Server: It is a type of server that provides service over the Internet protocol. All kinds of web pages published on the Internet are hosted on web servers. It should be hosted in a data center with high internet connection speed because it receives access requests from many clients.

- Application Server: It is a type of server that hosts applications. Web and desktop applications can be run on application servers. Application servers act as middleware between web servers and sql servers. It is deeply related to API technology.

- Database Server: They are servers that provide database application service. It transfers the data requested by the users to the front end. Database servers often host complex large data sets.

- Computing Server: They are servers that are used to process a very large amount of information. It has a powerful CPU and RAM.

- Mail Server: They are servers that are built for messaging, used between e-mail senders and receivers. It generally provides data transfer service in POP3 and IMAP protocols.

- Media Server: They are servers that are configured to transfer all kinds of images, sounds and videos.

- Proxy Server: They are servers that provide router service between client and server. It is generally used by banks and corporate firms for security purposes.

- File Server: They are servers that provide file transfer on the network.

Energy Consumption of Servers

Servers are costly devices in terms of both service costs and electricity consumption costs.[4] Continuous cooling is required to remove heat generated by the machine's processor from the server. In the United States, where the most data center investment is made in the world, server-based energy consumption constitutes 2.5% of all energy consumption in 2010. Due to the continuous increase in demand and need for data centers, these energy consumption rates are expected to increase exponentially in the coming years.

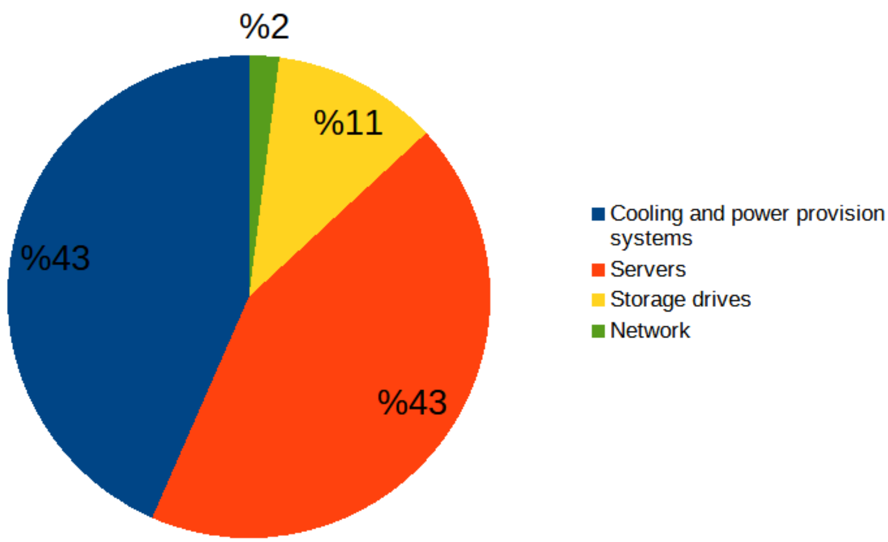


Figure 2. Fraction of data center energy/electric consumption in the United States, 2014

In order to minimize the damage of increasing energy consumption to the global climate, the use of environmentally friendly energy should be expanded. The table below provides an estimate of how the electricity consumption of data centers will increase on a yearly basis.

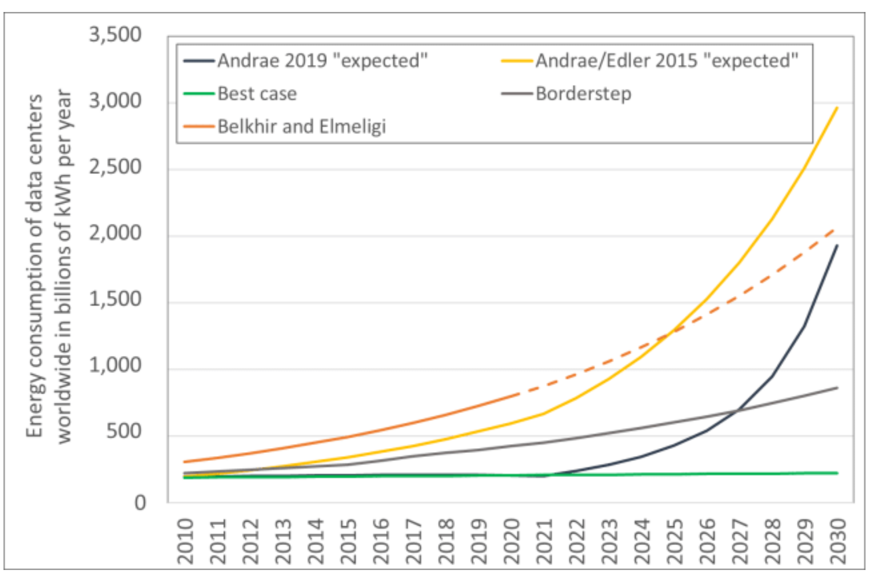


Figure. Energy consumption of data centers (worldwide)

Data Centers

Classification of Data Centers

Data centers are classified according to the standards prepared by Uptime Institute. The main criterion in classification is the concept of system availability. Classifications can be made according to criteria such as the quality of the infrastructure service of the enterprise, the operating time (uptime) of the system, and the infrastructure performance. Companies that meet these criteria can achieve their growth targets in a systematic way step by step.

Space Type	Typical Size	Typical IT Equipment Characteristics
Server closet	<200 ft^2	1-2 servers No external storage
Server room	<500 ft^2	A few to a few dozen servers No external storage
Localized data center	<1000 ft^2	Dozens to hundreds of servers Moderate external storage
Mid-tier data center	<5000 ft^2	Hundreds of servers Extensive external storage
Enterprise-class data center	5000+ ft^2	Hundreds to thousands of servers Extensive external storage

Table 1. Classification of servers according to the area they occupy

4 different classifications have been determined for the data center infrastructure. Each class is called a “Tier”. Each Tier corresponds to a specific function. Tier standards are also inclusive, that is, they include the previous standard and its criteria. Compliance of data centers with Tier standards contributes to both local legal rules and industrial standardization.

	Tier I	Tier II	Tier III	Tier IV
Number of supply paths	1	1	1 Active 1 Passive	2 Active
Redundancy (N corresponds to number of supply paths)	N	N + 1	N + 1	2 (N + 1)
Simultaneously maintenance enabled	no	no	yes	yes
Critical errors’ tolerance	no	no	no	yes
Availability A_0 (%)	99.671	99.749	99.982	99.991
Number of events (Downtime)	1–2 over 4 h/1 year	2 over 4 h/2 year	2 over 4 h/5 years	1 over 4 h/5 years
MTTR in hours/year	28	22	1.6	0.4

Table 2. Comparison of data center tier classes

Tier I

Tier I is a standard used to describe the core capabilities of data centers. In order to reach the Tier I standard, it is necessary to create a special place with an infrastructure instead of an office level server area. Uninterrupted power must be supplied as infrastructure requirements. In addition, it is necessary to have special cooling equipment that continues to work 24/7 without interruption and a motor generator that will protect it from long-term power cuts.

Tier II

It covers all the criteria of the Tier I standard, which is 1 level lower than Tier II itself. It is basically a standard produced for medium-sized businesses. It is aimed to increase security against interruptions. Redundant power and cooling components are included in the Tier II standard.[5] These spare components include uninterruptible power supply (UPS), coolers, pumps, motor generators.

Tier III

It is a standard which is developed for large enterprises. It incorporates multiple power and cooling units. A backup distribution path is created. Therefore, there is no need to shut down the system for equipment replacement and equipment maintenance. The system uptime rate increases.

Tier IV

It covers Tier I, II and III standards. It can withstand 96 hours of interruption in addition to other standards. A more rigorous study is carried out on the installation location of the data center. There is a staff team working 24/7. Unaffected by individual equipment failures and distribution path interruptions. It has a more durable and more fault-tolerant structure. High security measures are taken. IT operations are less likely to be interrupted.

Colocation Data Center

Where customers physically host their servers. Customers have control over the design and use of their servers and equipment. The data center provides power and cooling support to customers' equipment. All processes related to the infrastructure are the responsibility of the data center. All technical needs of the servers are met by the data center (internet connection, security, cooling, technical support, etc.).

Enterprise Data Center

They are data centers used by companies for corporate purposes. It is open to the private use of only one company. The firm is responsible for the entire IT operation of the data center. Although the initial setup cost is high, it is preferred by corporate companies. Since it is for private use, it can be customized in terms of software and hardware. It generally has a flexible structure.

Hyperscale Data Center

Hyperscale data centers are technically a type of data center in which there is at least 1 server every 2 square feet. The main purpose is to fit the most servers in the least space. It is generally used by IT companies (Google, facebook, yandex) with very high traffic websites or used by telecommunication companies. These data centers use high-density server racks. Energy consumption and cooling costs in these data centers are very high.

Cloud Solutions

Cloud solutions are a computing service provided by hyperscale data centers. There are 3 different types of services as IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service). It prevents customers from wasting time on maintenance and technical problems of servers and allows them to focus on their own work. It is much simpler to use than services received from other data centers.

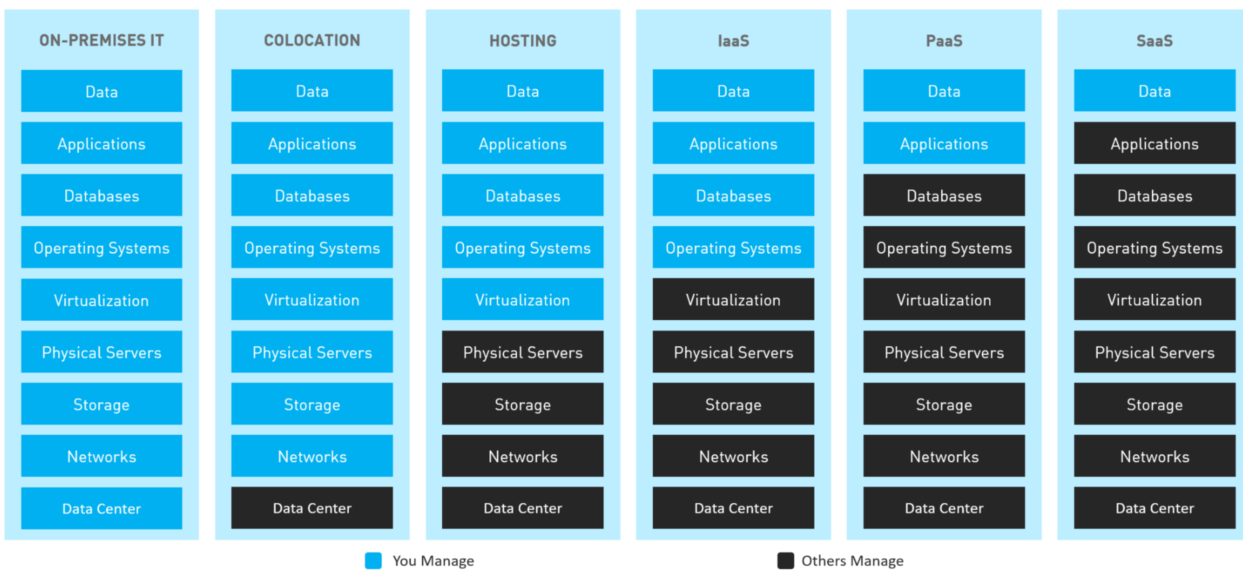


Figure 3. Comparison of cloud and data centers by their function

Managed Data Center

They are data centers that provide IT operation services by receiving hosting services from 3rd party data centers. Managed Data Centers can be fully or partially managed. It can be scaled according to the characteristics of the service provided.

Micro Data Center

Micro data centers are the smallest data center solution that can contain basic components such as power, cooling, security, software. It is a data center with basic features by combining the desired features in a modular form. It can be scaled on demand.

Data Center Cooling Technologies

Calibrated Vectored Cooling (CVC)

It is generally used for cooling high density servers. It is aimed at making the fans working for cooling purposes work in an optimized way. The airflow path is designed to pass over the components that produce the most heat. The airflow is optimized according to the operating state of the server. It also ensures the optimal number of fans to operate.

Cold Aisle/Hot Aisle Design

It is basically based on not mixing the hot air produced by the servers with the cold air produced by the cooling system. The hot air produced is transmitted to the cooling system through the corridors created. The cold air produced by the cooling system is transmitted directly to the heated server without mixing with the hot air. Designing server cooling systems in this way provides energy efficiency. Empty shelves in server cabinets are filled with space panels to prevent wasting cold air.

Computer Room Air Conditioner (CRAC)

It is the most widely used cooling technology in system rooms. The working principle is as follows. [6]A certain gas is liquefied with the help of a compressor and the resulting heat is released to the outside. After this process, the pressure on the liquid is reduced with the expansion valve and the heat is withdrawn from the environment and converted back to gas. The system works with compressors and fan units. It is one of the oldest air conditioning systems.

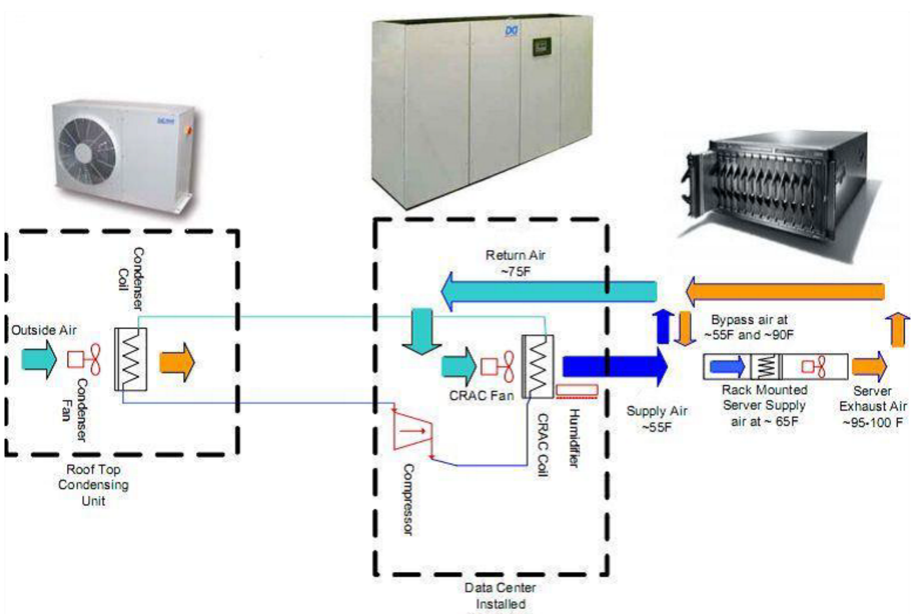


Figure. Working diagram of Computer Room Air Conditioner

Computer Room Air Handler (CRAH)

It is preferred by large-capacity data centers. It works in principle similar to CRAC systems. Unlike the CRAC system, the system has water instead of gas. The system that cools the water is called a chiller. It is more efficient than the CRAC system.

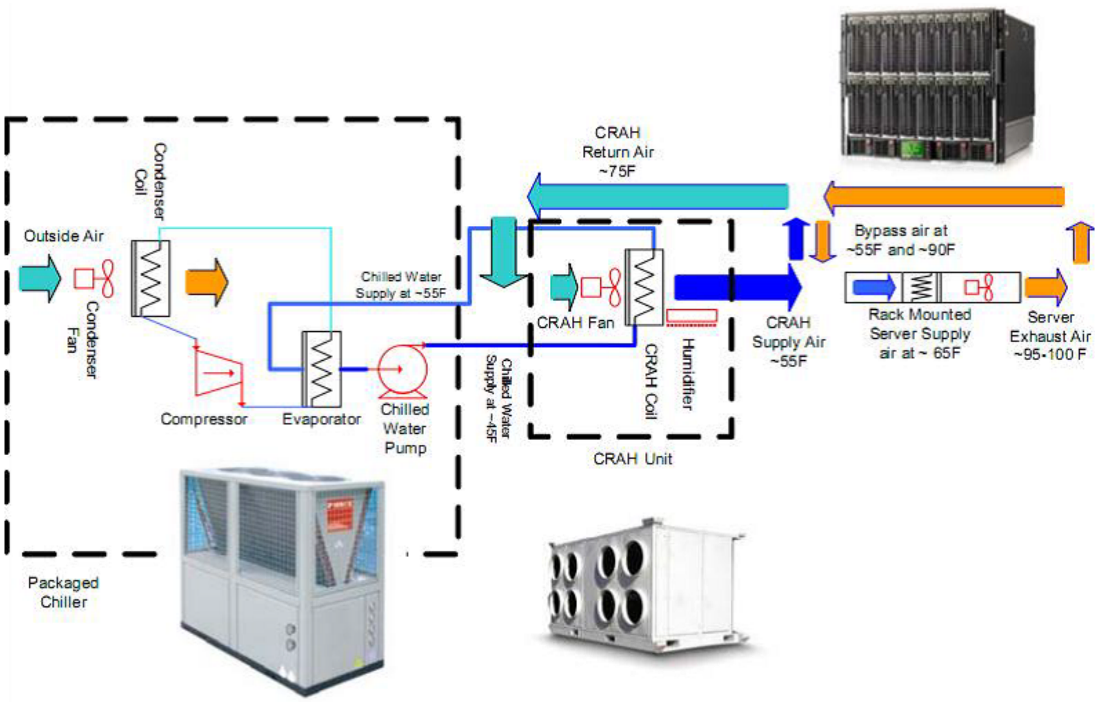


Figure 4. Working diagram of Computer Room Air Handler

Evaporative Cooling

It is one of the oldest known cooling methods. It works on the same principle as cooling the body through sweating. As the air evaporates while passing over a surface wet with water, the evaporated water draws heat from the surface, this method is called evaporative cooling. This system is cheaper as there is no compressor or refrigerant in this system.[7]

Free Cooling

It works based on the principle that the air used in the cooling system is drawn from the outside environment instead of being reused by recirculating it continuously. It is not a method that works in hot climate countries. It is a very convenient system in terms of energy efficiency.

Liquid Cooling

Chilled Water System

It works with the principle of sending the cooled water to the heated area through coils and returning this water, which absorbs the heat, to the cooler again. It is used in areas such as air conditioning of servers and air conditioning of residences. Since the cooled water is delivered directly to the target area, it is more efficient than air-based cooling systems.

Immersion System

It is a cooling system made using non-conductive, non-flammable dielectric fluid. Equipment which is immersed in dielectric liquid is cooled more efficiently than other cooling methods. [8]Because liquid absorbs heat much more efficiently than air. The heat is then cooled in the cooling section and given back to the dielectric liquid system in a cooled form.

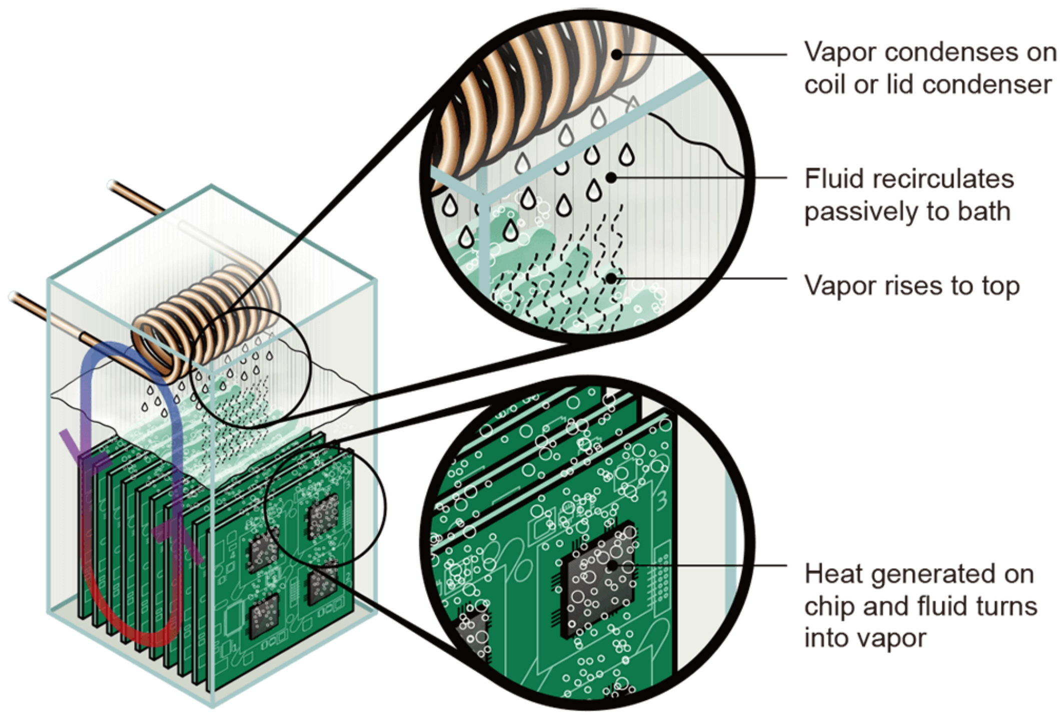


Figure. Immersion cooling working principle

Server Rack Cabinets

Server cabinets are areas where servers are stacked and organized in data centers. Sizes vary depending on the intended use. For example, in hyper-scale data centers, server cabinets should be smaller. Thus, more servers can be fitted in a smaller space. There are various types according to their functions.[9]

The industry standardized shelf size is 19 inches. The vertical area measure, represented by U, indicates how large the models are. Firms carry out production by considering these dimensions.

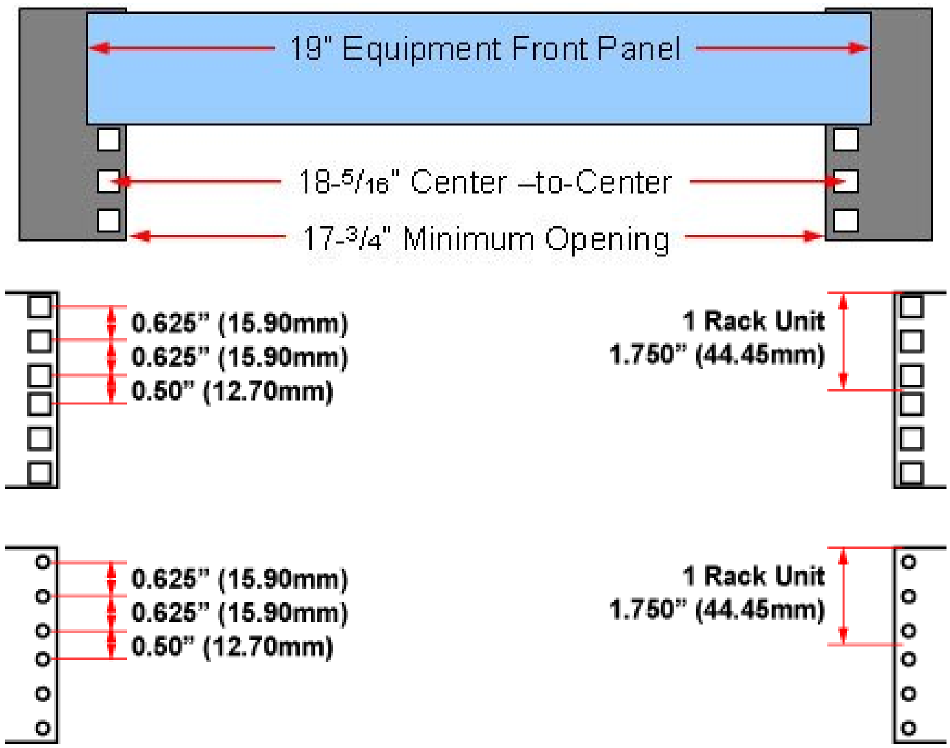


Figure 5. Dimensions for server rack cabinet

Open Frame Racks

It is a cabinet type consisting of only a frame. It doesn't have any cover. Can be floor or wall mounted. Its price is lower than closed cabins, it is economical. Two different variants are available

Two-post Open Racks

It is the most economical cabin type. It has only two post. Therefore, its usage area is more limited.Two-post racks can only accommodate smaller equipment, such as patch panels and switches. Ideal for small offices.

Example two-post open rack
Dimensions: 47.37"H (24U) x 20.81"W x 15.04"D
Features:
10-32 tapped rails
Includes 25 10-32 rack screws
Includes four ¼-20 grounding studs
Gangable
Ships knocked down
800 lb. weight capacity
19” EIA compliant

Four-post Open Racks

It is less economical than two-post cabinets. However, it is more robust and its usage area is wider. It is widely used in large-scale data centers. Their weight capacity is large. Heavy equipment such as UPS can be mounted.

Example four-post open rack
Dimensions: 84"H x 20.6"W x 24"D
Rack Spaces: 45 RU of EIA 310-D compliant mounting
Weight Capacity: Stand Alone 1,000lbs, Networked 1,250 lbs.
Features:
Mounting rails #12-24 threaded
Assembly hardware included
Mounting hardware included (50 x 12/24 type 23 screws)
Ships unassembled, 3 packages.
Toe-out or toe-in mounting

Rack Enclosures

It is a type of server cabinet with side panels and doors. It protects the server against external impacts. It prevents access by unauthorized persons. It isolates the server from the external environment.

Floor Standing Rack Cabinets

They are cabinets that do not require wall mounting in indoor areas. It usually has a higher weight capacity than wall-mounted cabinets. It has a deeper interior volume. It mostly has wheels to have mobility function. It is very easy to install.

Example floor standing rack cabinet
19" Floor Standing Server Rack Cabinet
37U (24"w x32"d x74"h)
(600x8000x1870mm.) (WxDxH),
Glass Door
(TEMPERATURE CONTROL PANEL, 4 fans,1 shelf, 1PDU)

Wall-mount Racks

It is a type of server cabinet that is designed for wall mounting. It is advantageous for light installations. Ideal for small businesses. The models have heights varying between 28-36 inches and a depth of 18 inches.

Example wall-mount rack cabinet
Rack Units: 9U
Dimensions: 22.45"W x 17.57"D x 19.6"H
Features:
150 lbs. weight capacity
Adjustable 10-32 tapped rails
16.82" maximum usable mounting depth
Locking acrylic door
Solid sides
Hanging bracket for ease of installation
Welded frame construction - 19" EIA compliant

Phase Change Materials

Thermal energy storage (TES) can be achieved by *sensible* energy storage, *latent* energy storage and thermo-chemical energy.[10] Among these methods, *latent energy storage* using **phase change materials** (PCM) are the most efficient energy systems due to **high storage density** and absorbing features while the melting is happening. In another part when the storage process is done, releasing the heat to the surroundings begins and this goes on.

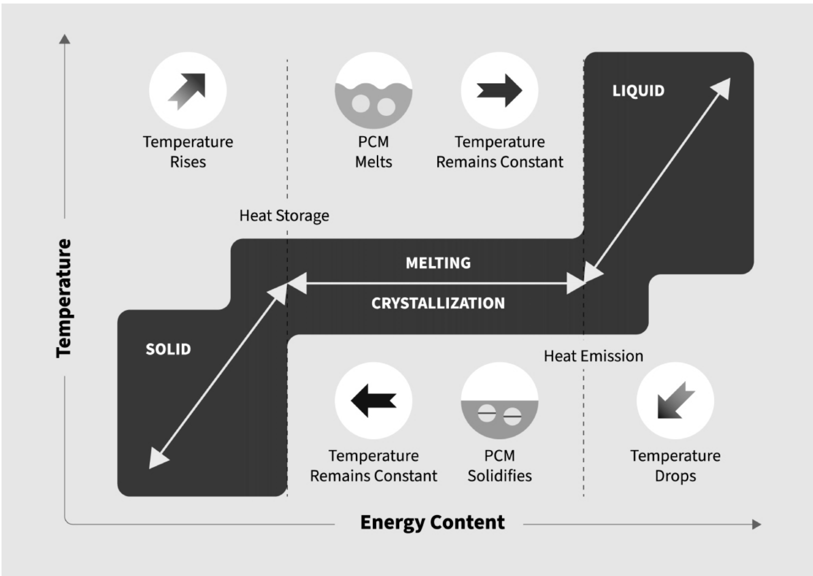


Figure 6. A graph of temperature vs energy content about PCMs

Heat storage capacity of a Phase Change Material can be found with an equation such as

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta H_m + \int_{T_m}^{T_f} mC_p dT$$

PCMs can be classified as of three types depending on materials' chemical properties. These are *organic*, *inorganic* and *eutectic* PCMs.[11]

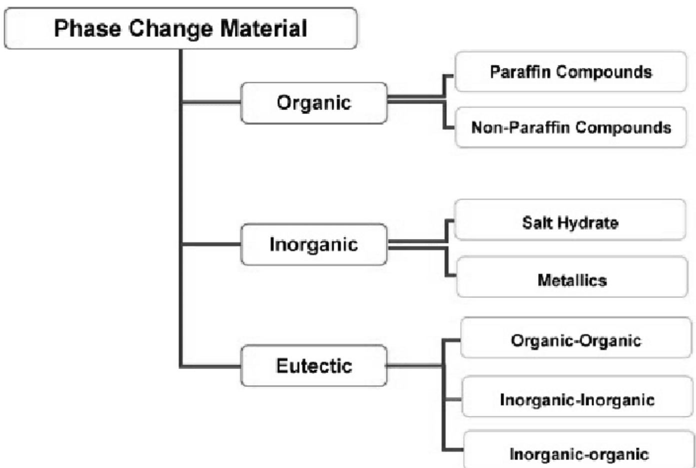


Figure 7. Types of PCM

Commercial PCMs That is Used at Industrial Grade

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 3. Specifications of Rubitherm RT35

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 capsules. This method is both cheaper and faster.

Organic Phase Change Materials

Organic PCMs have relatively lower phase change enthalpy[12] and thermal conductivity. These organic PCMs are **paraffins**, fatty acids, polyhydric alcohols and sugar alcohols.

Advantages and Disadvantages of Organic PCM

- **High temperature range.**
- **Paraffins have no tendencies to super cool.**
- **Stable for more cycles.**
- **No corrosiveness.**

- **Pure paraffins are expensive.**
- **Paraffins are flammable.**
- **High changes in volume during the phase transition.**

Inorganic PCMs	Organic PCMs	Eutectics
$CaCl_2.6H_2O$	Paraffin C_{14}	Capric + lauric acid (65+ 35 mol%)
$Na_2CO_3.10H_2O$	Paraffin C_{16}-C_{18}	Mystiric + Capric acid (34+ 66 mol%)
$Mn(NO_3)_2.6H_2O$	Capric acid	Capric + lauric acid (45+ 55 mol%)
$LiClO_3.3H_2O$	Stearic acid	Urea (37.5%) + acetamide (63.5%)
$Na_2HPO_4.12H_2O$	Palmitic acid	$MgNO_3.6H_2O$ (58.7%) + $MgCl_2.6H_2O$ (41.3%)
$KF.4H_2O$	Oleic acid	$CaCl_2.6H_2O$ (66.6%) + $MgCl_2.6H_2O$ (33.3%)
H_2O	Polyethylene glycol 200-10000	$CaCl_2$ (48%) + NaCl (4.3%) + KCl (0.4%) + H_2O (47.3%)
$CaBr_2.6H_2O$	Erythritol	$Ca(NO_3)_2.4H_2O$ (47%) + $Mg(NO_3)_2.6H_2O$ (33%)
NaCl	1-tetradecanol	
KNO_3	Naphthalene	

Table 4. List of commonly used PCMs.

Paraffin Compounds

One of the paraffin compounds which we use in our project is **Paraffin waxes.** They are solid-liquid PCMs and widely applied because of their properties such as,

- small amount of supercooling
- non-toxicity
- non-corrosiveness

It is our best choice according to its *high thermal energy storage capacity* and *melting temperature range* between **-9 °C** and **100 °C**.

However, the practical applications are not so easy due to their inherent drawbacks including *low thermal conductivity* and *leakage during the melting process*. By preventing the leakage while the phase change occurs and increasing the transfer of heat is highly considerable for possible utilization of paraffin waxes.

Non-Paraffin Compounds

Polyethylene Glycol Fatty Acid and **Esters** as *Phase Change Materials* are greatly important as *non-paraffin organic compounds*.
Fatty acids have higher heat of fusion compared to the paraffin wax.These acids show repeatable melting and freezing and minimum supercooling. The general formula that defines all fatty acids is given by **$CH_3(CH_2)_{2n}$-COOH**.

On the other hand, their great drawback is their high cost, which is about 2–2.5 times more than that of paraffin wax. It must also be noted that they are corrosive. PEG, having general formula **H-(O-CH_2-CH_2)n-OH**, is studied as phase change material. Their properties can also be described as *high phase change enthalpy*, *variable transition temperatures*, *chemica*l and *thermal stability*.

Inorganic Phase Change Materials

Inorganic PCMs have high thermal storage capacity and also good thermal conductivity but they can go through phase segregation with repeating cycles and there is a danger of subcooling and this can cause corrosion to metal containers. It must be noted that inorganic PCMs include the hydrated salts largely.

Salt Hydrate

Inorganic PCMs (M_nH_2O) such as *Salt Hydrates* can be of assistance in the need for making more stable application of solid-liquid PCM composite matrix. This would prevent the melted PCM's flowing and also enhance the thermal conductivity of the matrix.

Figure 8. Some figures showing the salt hydrates

Metallics

Metallic materials have a rather high heat of fusion and these materials also show high latent heat values.They are non-flammable, cheap, and available. Nevertheless,it has some disadvantages. These problems have led the researchers to find a better solution. Some of these disadvantages are **instability** which causes *phase decomposition* and *improper re-solidification*.

Eutectic Phase Change Materials

Eutectics can be **inorganic** or **organic** depending on the mixtures of two or more PCMs. Although eutectics have *stable phase separation* and *good phase change enthalpy*, extensive research is needed to find eutectics with *suitable transition temperatures*.

An organic eutectic PCM is a mixture of two or more organic PCMs. It behaves as a single component and freezes to an homogeneous mixture of crystals and then melts at the same time without separation. Many of the organic eutectics can be tailored to almost any wanted melting temperature for Thermal Energy Storage (TES) systems.

Applications of Phase Change Materials

For containment of PCMs, some methods have been found. These are

- Using a porous or layered material
- Microencapsulated PCMs

MicroPCMs have PCMs in the core and these are surrounded by organic or inorganic material as the shell. MicroPCMs are used in solar energy storage, air conditioning, building energy conservation and in thermal regulating fibers and textiles.

Encapsulation

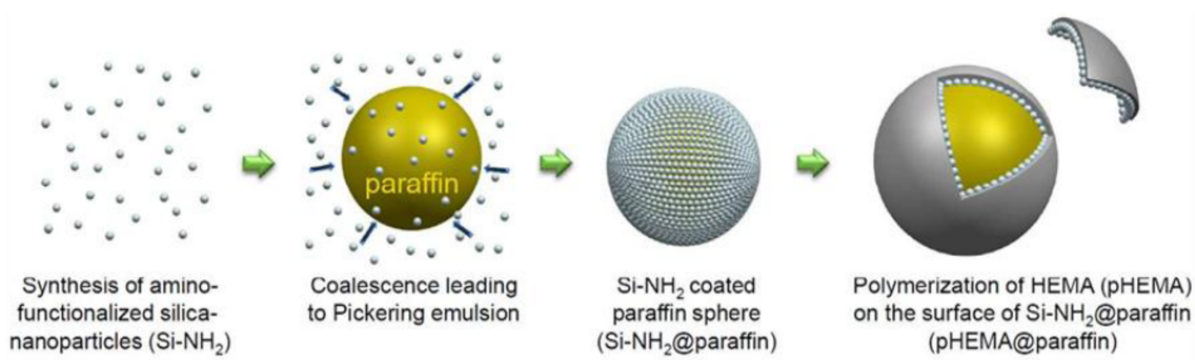


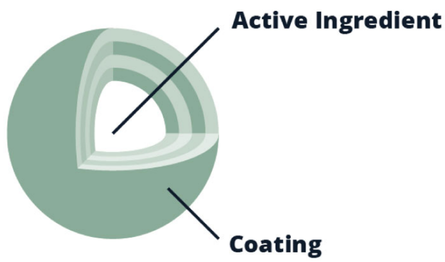
Figure 9. Schematic representation of preparation of paraffin encapsulated poly(HEMA)

Micro-encapsulation

Microencapsulation is the **effective** way to use PCMs as core, which is covered with shells made from polymers. The resulting material called *PCM microcapsule* can prevent the leakage of interior PCMs and increase the heat transfer area. Different techniques are followed to have a more strong shell, to increase the thermal conductivity of the material and add some other properties to the microcapsule.

Macro-encapsulation

It is the most used encapsulation application and it is done by encapsulating PCM into tubes, panels, and spheres. The macro-capsulated PCM acts as a heat exchanger. Features such as the material, shape, size of the encapsulation package greatly change the performance of the PCM. In the field of cooling of servers with PCM, macrocapsulation techniques can be used at many scales. For example, it is a suitable solution for cabinet-level cooling.



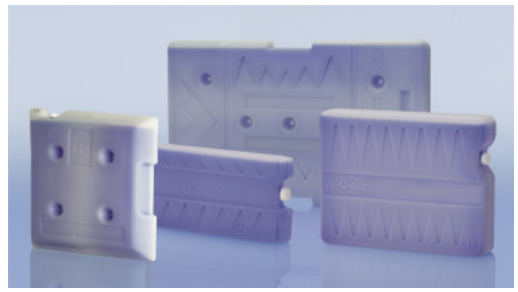


Figure. Micro-encapsulation and macro-capsulation technology

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.

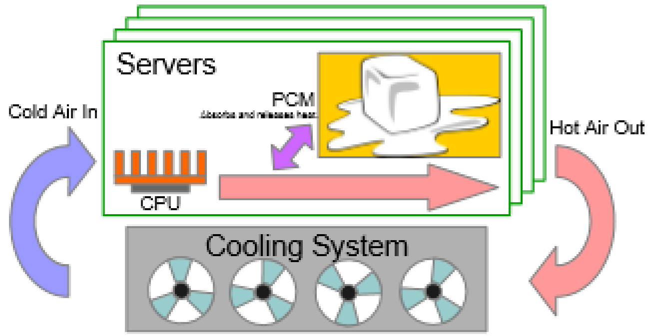


Figure 10. Integrating PCM in Warehouse-Scale Computers

To prevent high server failure, the cooling system must be able to handle the peak demand of the data center. Further, the cooling system also may become insufficient as servers undergo upgradation or replacement. 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.

Thermal Time Shifting

Thermal time shifting (TTS) proposes to reduce the cost of datacenter cooling systems by temporarily decoupling work done in a datacenter from the load on the cooling system in that datacenter. TTS leverages the diurnal cycle created by user facing traffic (such as web search queries, social media interaction, etc.) During the day, when users in a datacenter's service region are awake and active, load is high and load is much lower during the late night and early morning when users are not active online. During the peak hours of the day, TTS stores excess heat in a phase change material (PCM) such as paraffin wax and releases it during the off hours to better balance the cooling load, thus enabling a smaller cooling system by overprovisioning.

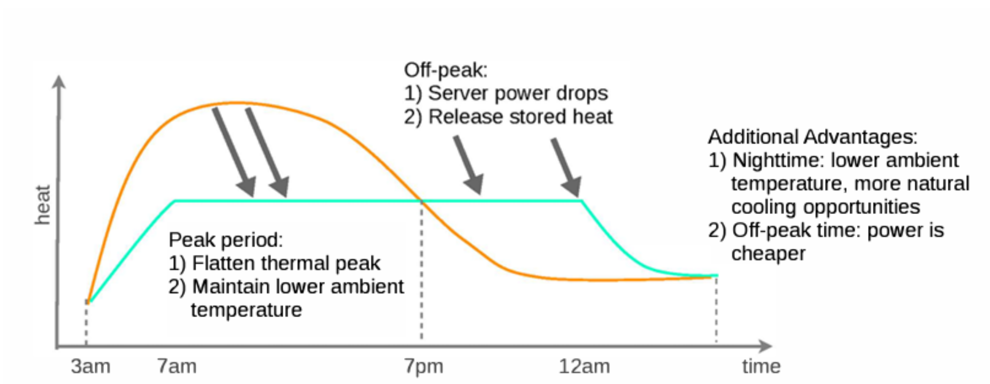
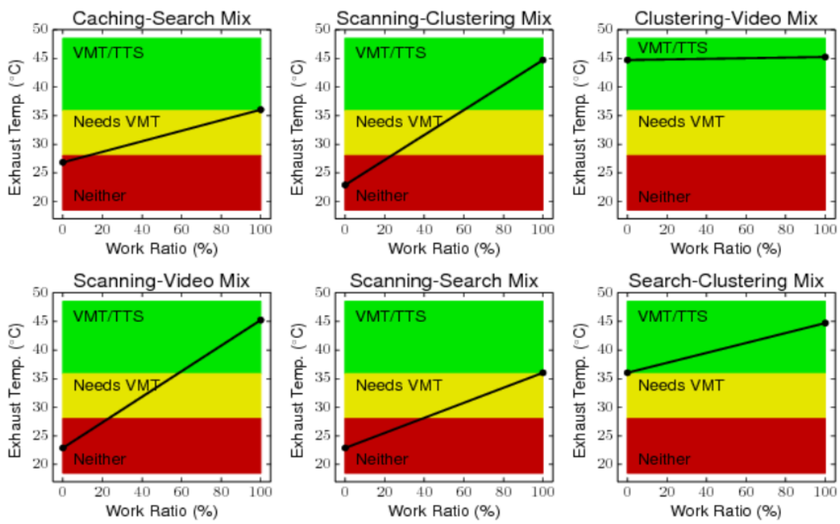


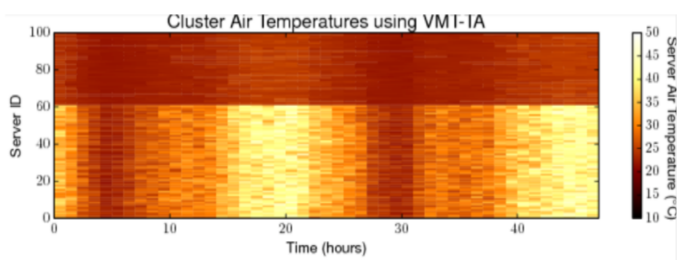
Figure. Thermal time shifting (TTS)

Virtual Melting Temperature

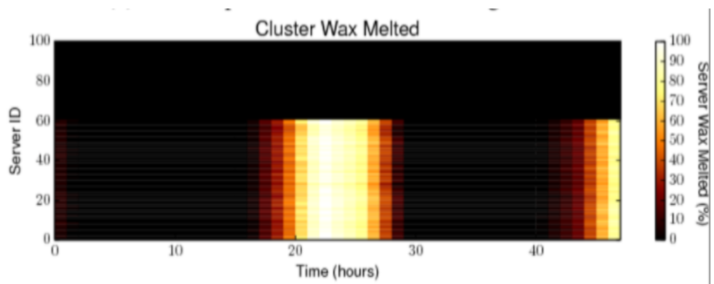
It is a thermal aware job placement technique that adds an active, tunable component to enable greater control over the datacenter's thermal output. It can also be defined as the active management of workload placement to create a more desirable thermal footprint for thermal energy storage.

Virtual Melting Temperature (VMT) technique can handle workload power mixtures that TTS alone is unable to cool. VMT does so in such a way that it induces melting of the PCM (and thus heat redistribution) at load and average temperature levels that are different than would happen with TTS, thus mimicking the operation of wax with a melting point that is different than the physical melting point of the deployed wax.





(a) Air temperatures at the wax using VMT-TA.



(b) Wax melted using VMT-TA.

Heat Sink

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature. In computers, heat sinks are used to cool CPUs, GPUs, and some chipsets and RAM modules.[1] Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light-emitting diodes (LEDs), where the heat dissipation ability of the component itself is insufficient to moderate its temperature.

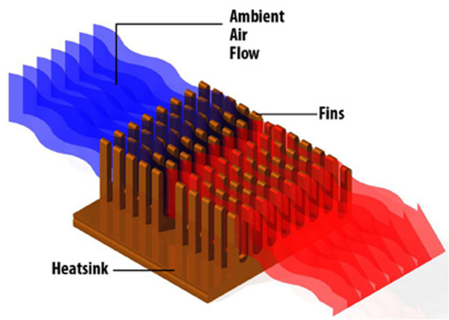


Figure 11. A heat sink illustration

A heat sink is designed to maximize its surface area in contact with the cooling medium surrounding it, such as the air. *Air velocity, choice of material, surface treatment* are factors that affect the performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the die temperature of the integrated circuit. Thermal adhesive or thermal paste improves the heat sink's performance by filling air gaps between the heat sink and the heat spreader on the device. A heat sink is usually made out of aluminum or copper.

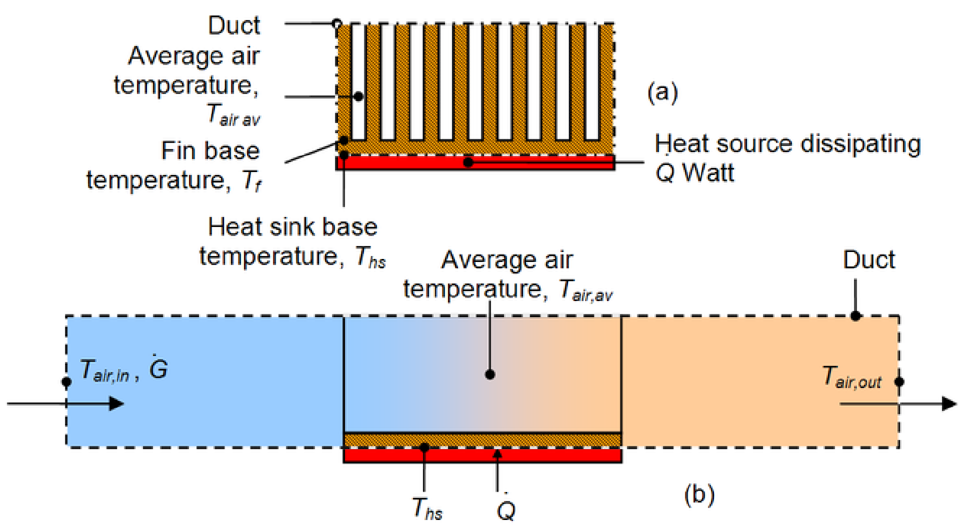


Figure. Sketch of a heat sink in a duct used to calculate the governing equations from conservation of energy and Newton's law of cooling

Heat Pipe

Heat pipes serve to carry thermal energy from one point to another. It is often used in electronic devices to evacuate waste heat from the chip. It is a two-phase system. The liquid under pressure in the pipe evaporates in the heated region and goes to the cold region where the pressure is low. The liquefied steam in the cold region goes back to the hot region and continues the cooling process again and again. This system, which is widely used in electronics, operates in the range of 20-150 degrees Celsius. Since it has no moving parts, it is generally long-lasting and maintenance-free. Copper material and water are generally used for cooling electronic systems.

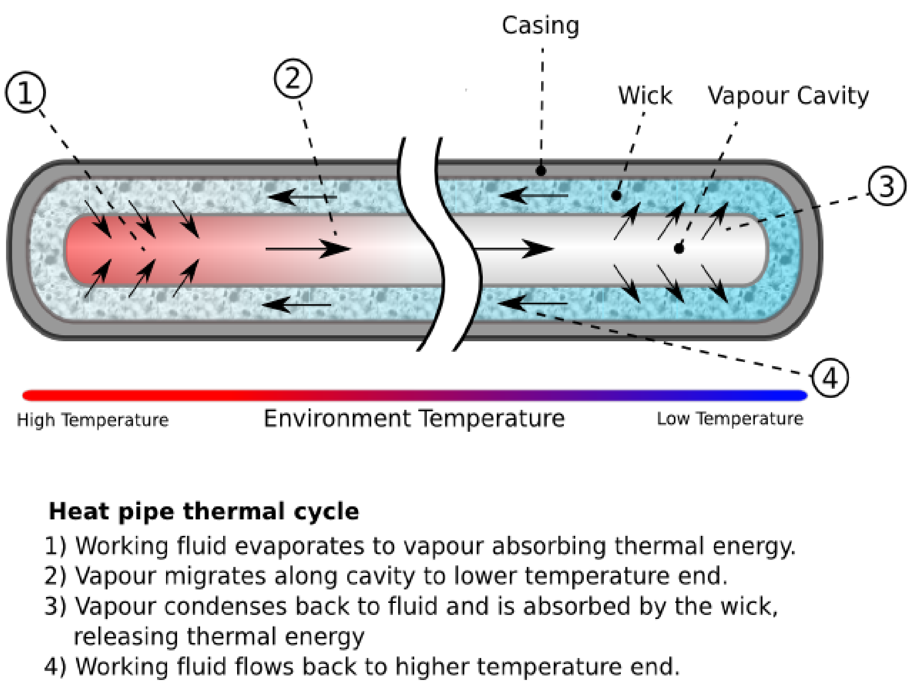


Figure 12. Heat pipe working cycle

Chip Level Thermal Management

It aims to cool the heat which is generated from the electronic chip directly at the source area. Heat can be transferred with an effective heat sink design or with the help of a micro heat exchanger. Micro-channel heat sinks are widely used.

Server Level Thermal Management

Cooling at this scale is not as micro-level as chip-level cooling. It is aimed to cool the printed circuit boards or the chip carrier. Generally, cooling is done with the help of cooling plates that come into contact with the circuit board.

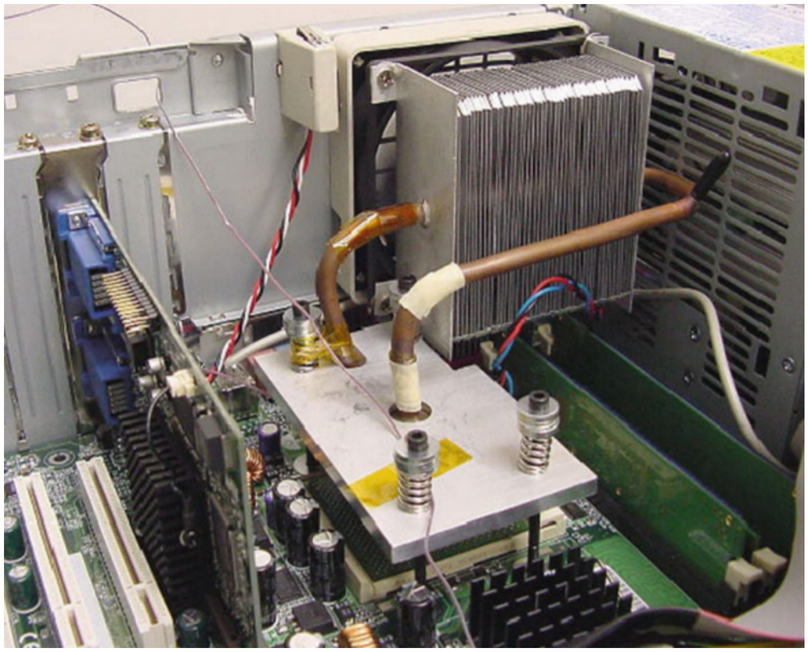


Figure. Server-level cooling system using two-phase water heater thermosyphon

Chassis Level Thermal Management

This level of cooling systems is mostly associated with the design of air-based cooling systems. Planning the placement of fans or designing air distribution paths can be given as examples. For example this large space can be used by one or more macro heat exchangers, which can transfer the heat from the chips of the servers into the cold air flowed by CRAC units at the cabinet scale. (1)

Cabinet or Rack Level Thermal Management

It is a widely used cooling method. Classical air-based cooling, liquid-based cooling or hybrid cooling techniques can be given as examples. CRAC and CRAH solutions are frequently used.

Room Level Thermal Management

Data centers are cooling the server rooms via CRAC units positioned on a raised floor. The cold aisle/hot aisle design technique is frequently used.

Plenum Level Thermal Management

At this scale, air duct platforms are installed above and below the server rooms. Hot air and cold air ducts are positioned separately.

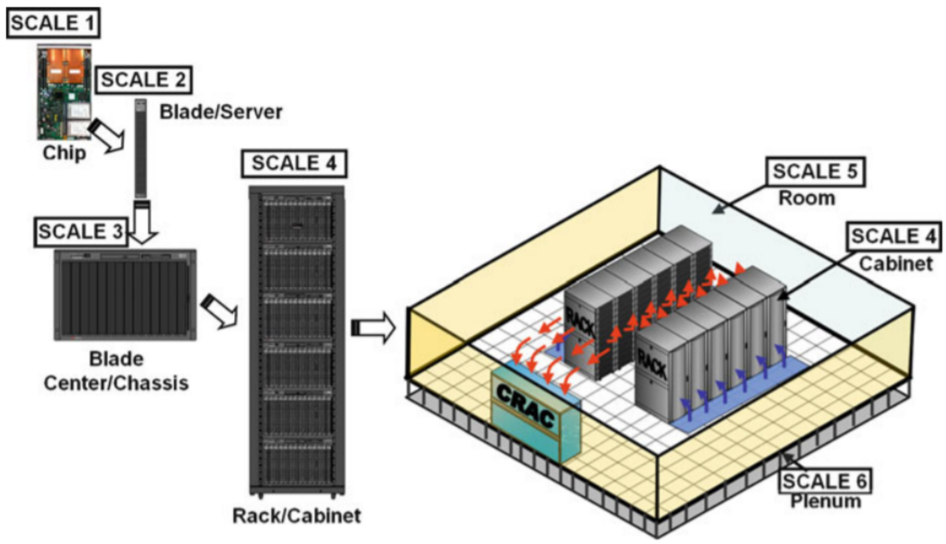


Figure 13. Multi-scale thermal management of data centers

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

	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 5. Recommended System Room Temperature and Humidity Values

Based on the values suggested by ASHRAE in 2008 in Table above, 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 the following table, 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 6. Environmental temperature for continuous operation for Servers

With given values in Table above, 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.

Heat Transfer

Heat transfer is a basic science that deals with the rate of transfer of thermal energy. It has a broad application area ranging from biological systems to common household appliances, residential and commercial buildings, industrial processes, electronic devices, and food processing. It is also a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy (heat) between physical systems. Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. Engineers also consider the transfer of mass of differing chemical species (mass transfer in the form of advection), either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system.[13]

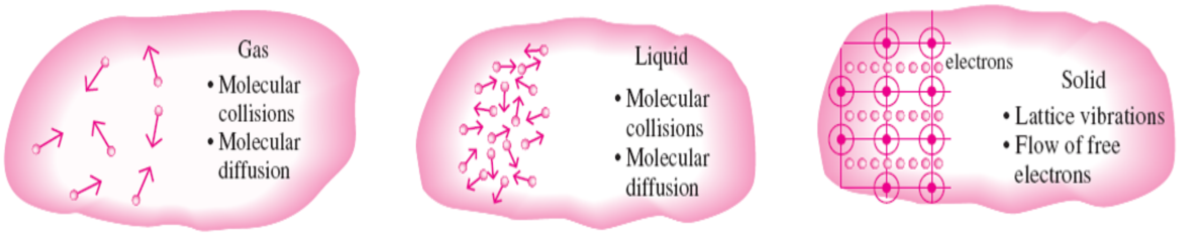


Figure. Distributive features of gas liquid and solid

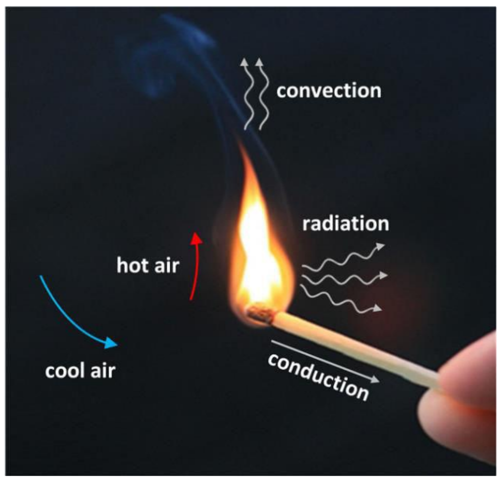


Figure 14. Basic mechanisms of heat-transfer in a match flame convection allowed by hot gasses

Thermal Conduction

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. It is also called diffusion, the direct microscopic exchange of kinetic energy of particles (such as molecules) or quasiparticles through the boundary between two systems. When an object is at a different temperature from another body or its surroundings, heat flows so that the body and the surroundings reach the same temperature, at which point they are in thermal equilibrium, such spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature.

Conduction can take place in solids, liquids, or gasses. In gasses and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. A cold canned drink in a warm room, for example, eventually warms up to the room temperature as a result of heat transfer from the room to the drink through the aluminum can by conduction.

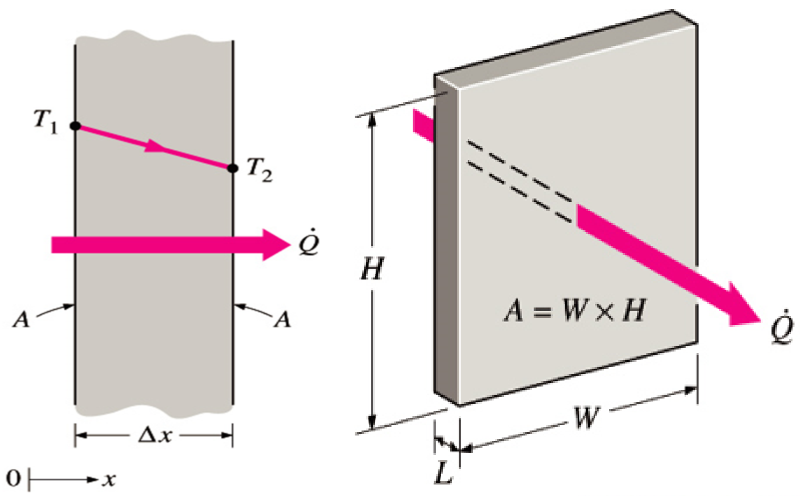


Figure 15. Heat conduction through a large plane wall of thickness Δx and area A

$$\text{Rate of heat conduction} \propto \frac{(\text{ Area })(\text{ Temperature difference })}{\text{Thickness}}$$

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x}$$

Where the constant of proportionality k is the *thermal conductivity* of the material, which is a measure of the ability of a material to conduct heat.

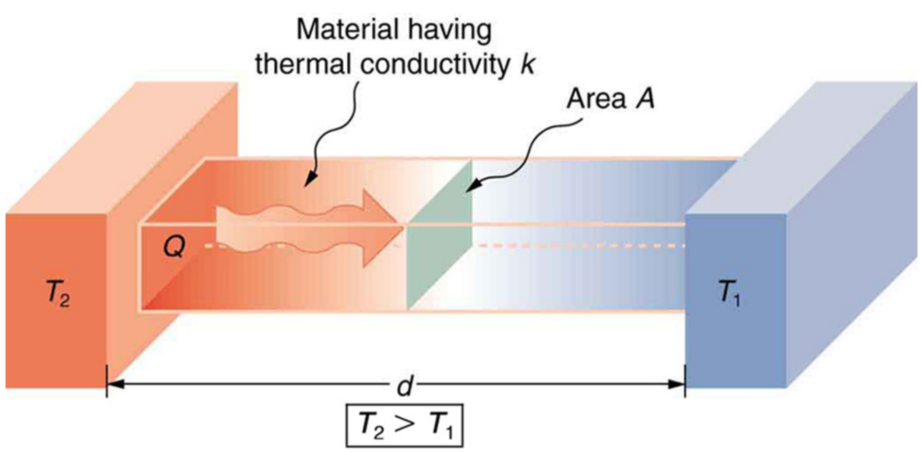


Figure. Heat conduction occurring at any material

Thermal Convection

Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion.It can also be described as the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfer.
In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

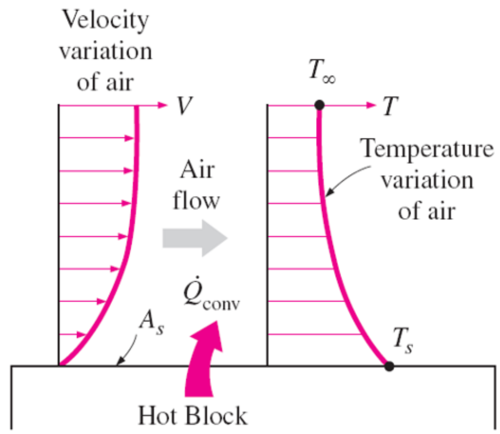


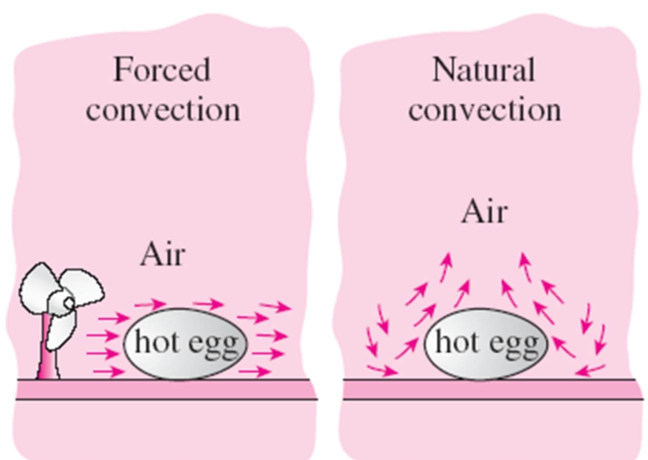
Figure 16. Heat transfer from a hot surface to air by convection

Forced convection

If the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind it is called *forced convection*.

Natural convection

If the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid it is called natural convection.



Heat transfer processes that involve change of phase of a fluid are also considered to be convection because of the fluid motion induced during the process, such as the rise of the vapor bubbles during boiling or the fall of the liquid droplets during condensation.

$$\dot{Q}_{\text{conv}} = hA_s(T_s - T_\infty) \quad \text{(W) Newton's law of cooling}$$

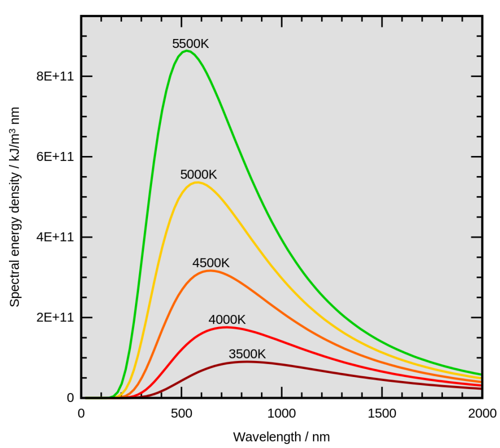
h convection heat transfer coefficient, $W/m^2 \cdot °C$
A_s the surface area through which convection heat transfer takes place
T_s the surface temperature
T_∞ the temperature of the fluid sufficiently far from the surface

Typical values of convection heat transfer coefficient

Type of convection	h, $W/m^2 \cdot °C$*
Free convection of gases	2–25
Free convection of liquids	10–1000
Forced convection of gases	25–250
Forced convection of liquids	50–20,000
Boiling and condensation	2500–100,000

Thermal Radiation

The energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules is called *radiation.* Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an intervening medium.In fact, heat transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth.



In heat transfer studies, it is interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. All bodies at a temperature above absolute zero emit thermal radiation. Radiation is a volumetric phenomenon, and all solids, liquids, and gases emit, absorb, scatter, or transmit radiation to varying degrees. However, radiation is usually considered to be a surface phenomenon for solids.

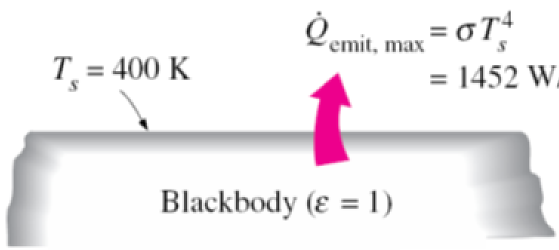
Blackbody
The idealized surface that emits radiation at the maximum rate.

$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \qquad \text{(W)}$$ **Stefan–Boltzmann law**

$\sigma = 5.670 \times 10^{-8}\ \text{W/m}^2 \cdot \text{K}^4$ *Stefan–Boltzmann constant*

Emissivity

A measure of how closely a surface approximates a blackbody for which Ɛ = 1 of the surface. 0≤Ɛ≤1



Blackbody radiation represents the maximum amount of radiation that can be emitted from a surface at a specified temperature.

Emissivities of some materials at 300 K

Material	Emissivity
Aluminum foil	0.07
Anodized aluminum	0.82
Polished copper	0.03
Polished gold	0.03
Polished silver	0.02
Polished stainless steel	0.17
Black paint	0.98
White paint	0.90
White paper	0.92–0.97
Asphalt pavement	0.85–0.93
Red brick	0.93–0.96
Human skin	0.95
Wood	0.82–0.92
Soil	0.93–0.96
Water	0.96
Vegetation	0.92–0.96

When a surface is completely enclosed by a much larger (or black) surface at temperature T_{surr} separated by a gas (such as air) that does not intervene with radiation, the net rate of radiation heat transfer between these two surfaces is given by

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s\left(T_s^4 - T_{\text{surr}}^4\right)$$

Radiation is usually significant relative to conduction or natural convection but may be negligible relative to *forced convection.*When radiation and convection occur simultaneously between a surface and a gas the total heat transfer rate can be found

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = h_{\text{conv}} A_s (T_s - T_{\text{surr}}) + \varepsilon\sigma A_s (T_s^4 - T_{\text{surr}}^4)$$

$$\dot{Q}_{\text{total}} = h_{\text{combined}} A_s (T_s - T_\infty) \qquad \text{(W)}$$

$$h_{\text{combined}} = h_{\text{conv}} + h_{\text{rad}} = h_{\text{conv}} + \varepsilon\sigma (T_s + T_{\text{surr}})(T_s^2 + T_{\text{surr}}^2)$$

$$\dot{Q}_{\text{total}} = h_{\text{combined}} A_s (T_s - T_\infty) \qquad \text{(W)}$$

Combined heat transfer coefficient, $h_{combined}$, includes the effects of both convection and radiation.

Phase Transition

Matter exists in three phases :Solid, Liquid, and Gas. Each phase has its own characteristic.The different characteristics of solid, liquid and gas phases result from differences in their molecular structure.If sufficient energy is added to the molecules of a solid or liquid, they will overcome these molecular forces and simply break away, turning the system to a gas. This is a *phase change process* and because of this added energy, a system in the gas phase is at a higher internal energy level than it is in the solid or the liquid phase.

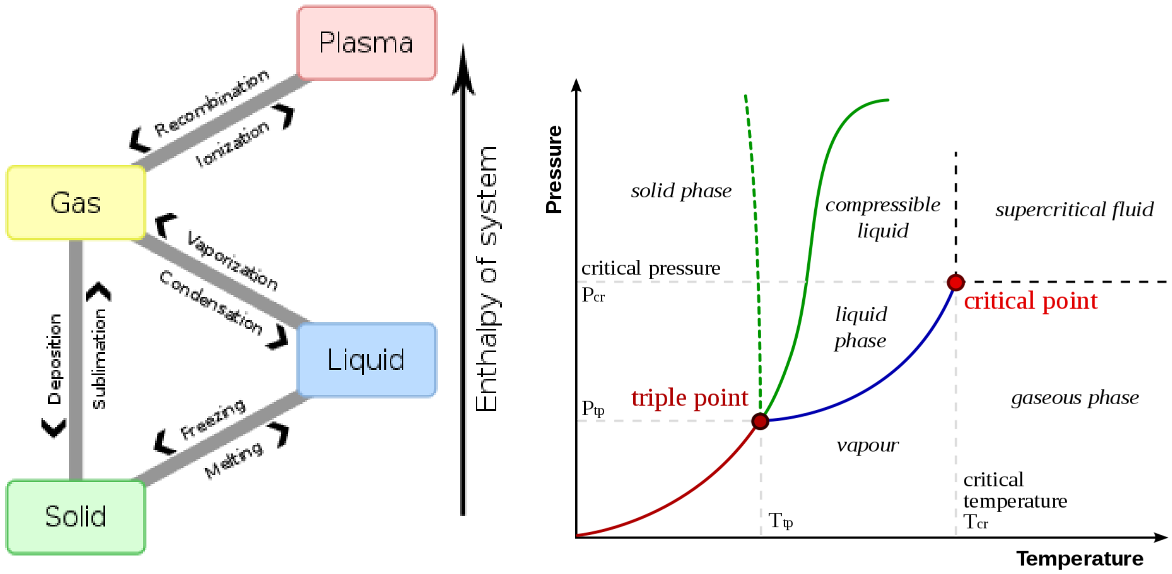


Figure. Transition and pressure to temperature diagrams

Thermal Energy Storage

With thermal energy storage (TES) systems, direct cooling-heating can be done without the need for chlorofluorocarbons (CFCs) that damage the ozone layer. It takes the need for electric energy and it can be prevented from overloading the electricity at the times when the electricity is needed the most.

Thus, it offers solutions that pollute the environment less by reducing the need for power plants and the use of fossil fuels.
Thermal Energy Storage methods are divided into two: thermal method and chemical method. The thermal method consists of *sensible heat* and *latent heat*, while the chemical method consists of reaction heat, chemical heat pump and thermochemical heat pump.

Sensible Heat

Sensible heat may be viewed as the kinetic energy of the molecules. It can also be described as the portion of the internal energy of a system associated with the kinetic energy of the molecules. The average velocity and the degree of activity of the molecules are proportional to the temperature. Thus, at higher temperatures the molecules possess higher kinetic energy, and as a result, the system has a higher internal energy.

Latent Heat

Latent heat may be viewed as the internal energy associated with the phase of a system. It can also be understood as energy in hidden form which is supplied or extracted to change the state of a substance without changing its temperature. Examples are latent heat of fusion and latent heat of vaporization involved in phase changes, i.e. a substance condensing or vaporizing at a specified temperature and pressure

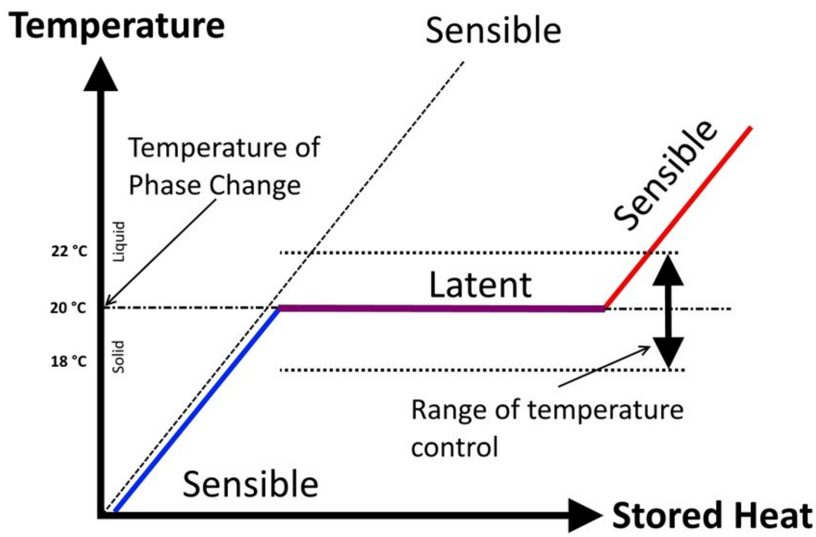


Figure 17. Sensible heat vs. latent heat and temperature control during the phase change

Experimental Procedure

Experimental Setup

Materials used for experiment 1 and experiment 2: Heating plate, thermocouple, precision balance, solid paraffin wax, liquid paraffin wax, beaker

Materials used for experiment 3 and 4: Styrofoam cabinet, MDF cabinet, lampholder (plastic and ceramic), light bulb (fluorescent and incandescent)

Materials used for Experiment 5: funnel, syringe, plastic bag with compartment, paraffin wax (solid and liquid), powder PCM, ceramic lampholder, light bulb (incandescent)

Materials used for Experiment 6 and 7: funnel, syringe, plastic bag with compartment, paraffin wax (solid and liquid), powder PCM, ceramic lampholder, light bulb (incandescent)

Creating the Server Cabinet

Configuration 1

Standard styrofoam foam (a material often used to insulate cold materials while transportation)
After the temperature test, the use of this model was abandoned.

Configuration 2

Server cabinet model created from MDF plates. The interior is covered with aluminum foil for heat insulation.

Creating the PCM Capsules

In the first experiment, oven bag was used for creating PCM capsules. Since the plastic film sealer does not give sufficient performance, the use of this material has been abandoned.

Oven bag

Plastic Film Sealer

In the second experiment, a ready-made plastic bag with compartment was used to fill the paraffin mixture. As a result of this experiment, it was concluded that the ready-made plastic bag with compartments is a more suitable material.

Plastic bag with compartment

Experiment 1. Determination of melting and boiling points of paraffin wax mixtures

Experiment 1.1.

The paraffin mixture was first boiled and then cooled.
* 26 grams of solid paraffin wax (melting range: 48-66 degrees Celsius)
* 13 grams of liquid paraffin wax (melting point: 24 degrees Celsius)
First of all, the boiling point of solid paraffin was investigated. Boiling of solid paraffin: 80-90-105-125 degrees Celsius values.
The boiling point of the mixture was investigated. The mixture starts to boil: 72-75-80-88-104-112 degrees Celsius.
The point at which the mixture started to solidify was investigated.
Solidification of the mixture: It began to solidify at 44 degrees Celsius.

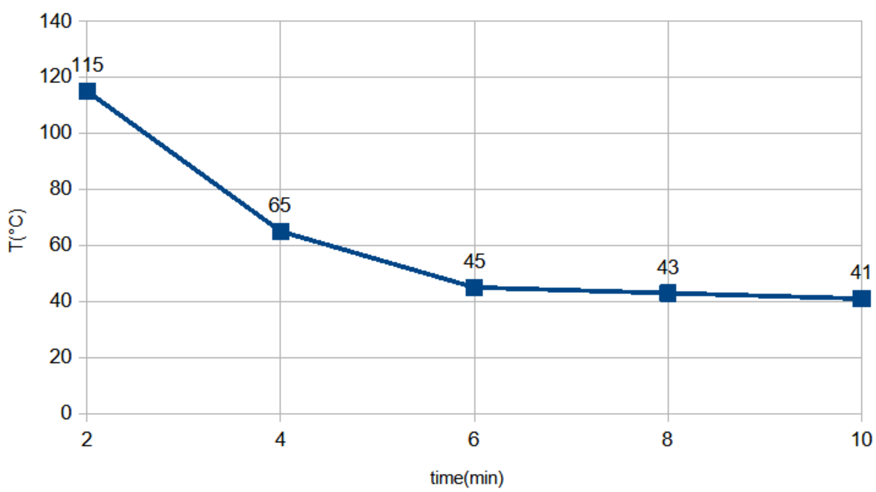


Table 7. Experiment 1.1. data table

Experiment 1.2.

The paraffin mixture was first boiled and then cooled.
* 77 grams of solid paraffin wax
* 100 grams of liquid paraffin wax
The mixture was first brought to the boiling point.
The mixture remained in its current phase (liquid phase) after 17 minutes. Then it started to solidify.

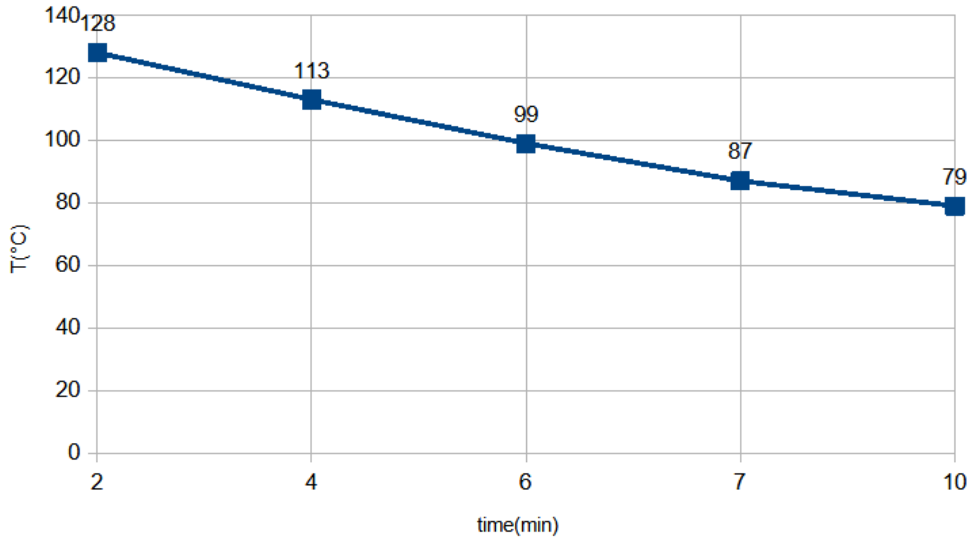


Table 8. Experiment 1.2. data table

Experiment 2. Determination of heat retention behavior of paraffin wax mixture

Experiment 2.1.

Paraffin wax heating experiment was carried out.
* 30 grams of solid paraffin wax
* 75 grams of liquid paraffin wax
The heating plate is set to 50 degrees Celsius.
The temperature of the heating plate is slightly higher due to previous use.
Conclusion from the experiment: This paraffin wax mixture does not have the phase change temperature ranges required for the project.

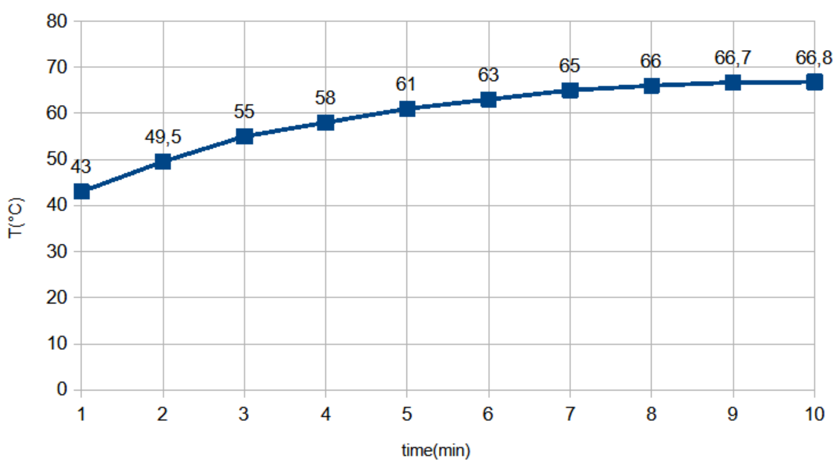


Table 9. Experiment 2.1. data table

Experiment 2.2.

Paraffin wax heating experiment was carried out.
* 40 grams of solid paraffin wax
* 75 grams of liquid paraffin wax
The heating plate is set to 50 degrees Celsius.
The temperature of the heating plate is slightly higher due to previous use.
The conclusion drawn from the experiment: The melting temperature of the formed paraffin wax mixture increases rapidly. Thermal ranges are not sufficient for use for the project.

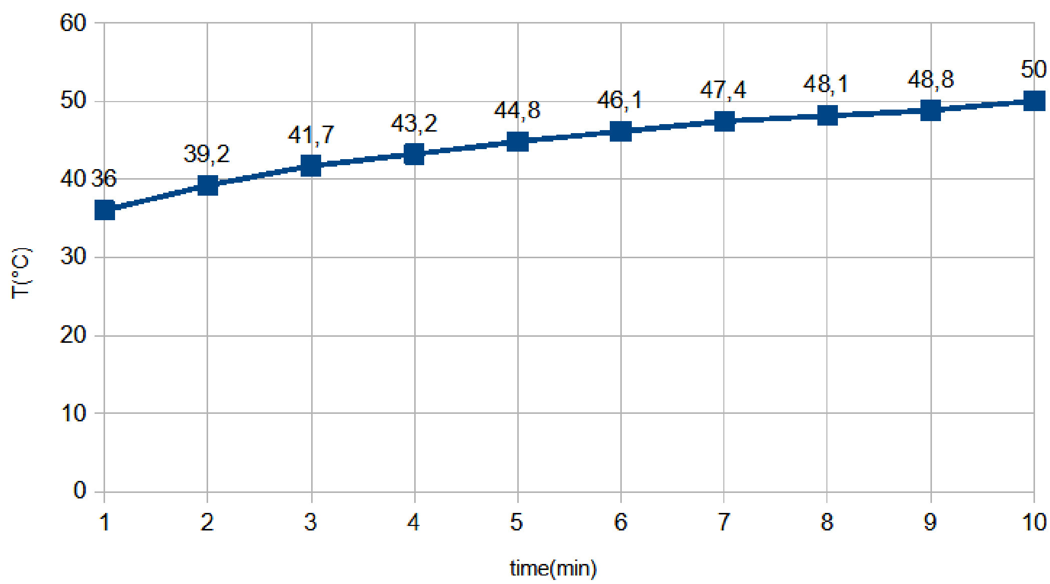


Table 10. Experiment 2.2. data table

Experiment 2.3.

Paraffin wax heating experiment was carried out.
* 50 grams of solid paraffin
* 75 grams of liquid paraffin
The heating plate is set to 50 degrees Celsius.
Since the heating plate was hot from previous use, it was cooled slightly and the experiment was carried out.
The result of this experiment gave the desired result. The paraffin wax ratio we need to use to cool the server cabinet should be 1:1.5.

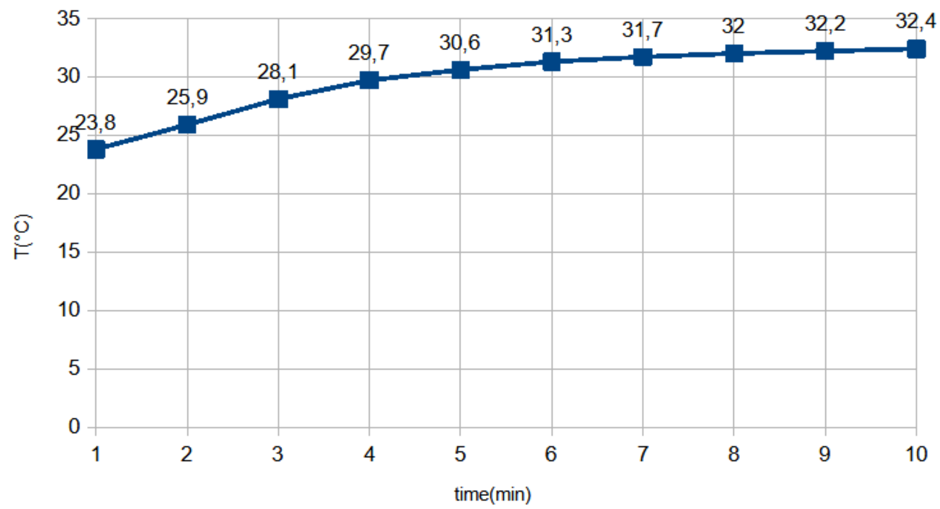


Table 11. Experiment 2.3. data table

Experiment 2.4.

Paraffin wax heating experiment was carried out.
* 75 grams of solid paraffin
* 75 grams of liquid paraffin

The heating plate is set to 50 degrees Celsius.
Since the heating plate was hot from previous use, it was cooled slightly and the experiment was carried out.
The conclusion drawn from the experiment: the produced paraffin wax mixture did not show the desired performance. Temperature changes are irregular and rapid, which is a feature we do not want.

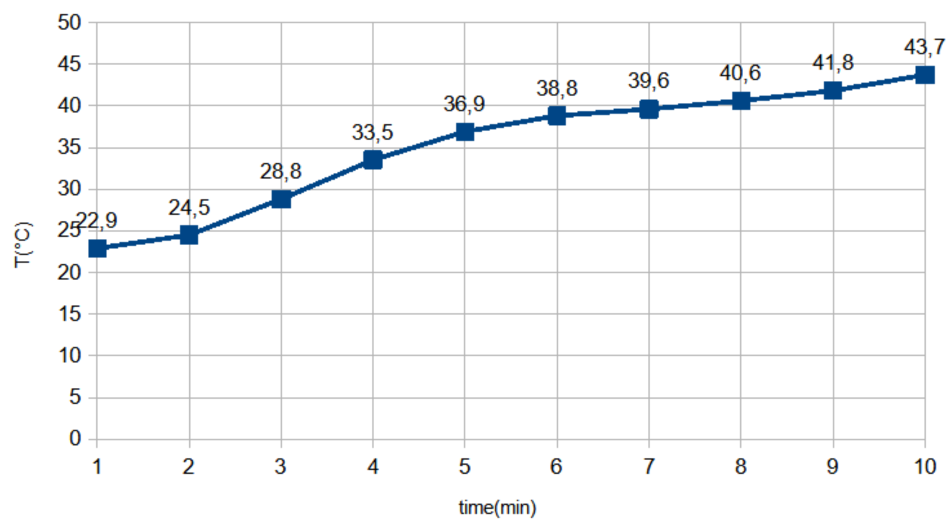


Table 12. Experiment 2.4. data table

Experiment 3. Determination of the heat resistance of the server cabinet by qualitative measurement

Heating test was carried out for the server cabinet made of styrofoam. (for configuration 1)
In this experiment, the thermal behavior of the styrofoam material was investigated.
Qualitative measurement was made.
* 10 Minutes, 23W Fluorescent Lamp Heating Test: No deformation occurred in the Styrofoam material.
* 10 Minutes, 72W Incandescent Lamp Heating Test: The thin styrofoam material in the middle of the experimental setup was deformed. No deformation occurred in the remaining styrofoam sections.
* 20 Minutes, 72W Incandescent Lamp Heating Test: At the end of the 16th minute, the thin styrofoam material on the cover of the experimental setup, used for insulation, was deformed.
* After 20 minutes, the plastic lamp holder started to melt.

Conclusion drawn from the experiment: Thin styrofoam material is not heat resistant and should not be used. Heat resistant ceramic socket should be used instead of plastic lamp holder..

Experiment 4. Performing thermal tests of the server cabinet

In this experiment, the interior of the cabinet was heated by incandescent lamps placed inside the server cabinet (for configuration 2). After the environment is heated, measurements were taken with a thermocouple at 10-minute intervals and the upper values at which the temperature in the cabin could reach were determined.

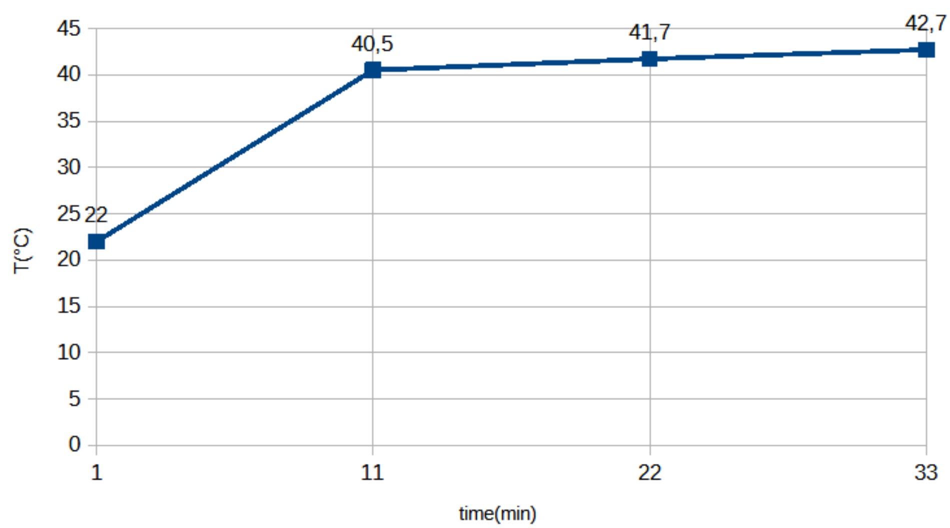


Table 13. Experiment 4. data table

The result obtained from the experiment: The created server cabinet which is made of MDF is sufficient in terms of insulating the heat.

Experiment 5. Creating PCM capsules and examining their effectiveness in the server cabinet

It has been determined that the paraffin wax mixture created in Experiment 2.3 can reduce the server cabinet to the desired temperatures. Therefore, it was decided that this material should be used for cooling the server cabinet.
Plastic bags with compartments were used to create the PCM capsules. The paraffin wax mixture was filled into the bag and fixed on the inner surface of the server cabinet.

Plastic bag with compartment filled with paraffin wax

All cells of the plastic bags with compartments are filled with paraffin wax and all 5 surfaces of the server cabinet are covered with these PCM capsules.

Fixing PCM filled capsules to the server cabinet

As you can see in the picture above, only 1 cell is filled, this process has been done for testing purposes only. Then all the cells were filled with PCM and the inner surface of the server cabinet was coated with them.
Thermal tests will be carried out to examine the performance of the product.The ambient temperature will increase with the light bulb placed inside the cabinet. The effect of paraffin wax on ambient temperature will be examined.

Experiment 6. Encapsulation and temperature testing of powdered PCM

First of all, the melting and freezing behavior of powder PCM will be examined as in experiment 1 and experiment 2. Then the powder PCM will be encapsulated and will be placed inside the server cabinet. Here, the phase change of the powder PCM will be examined by giving heat to the inside of the cabinet by means of a light bulb.

Experiment 7. Simultaneous temperature tests of paraffin wax-based PCM and Powder PCM

Paraffin wax-based PCM will be placed on the right side of the server cabinet, and powder PCM will be placed on the left side of the server cabinet. After the cabinet is covered with PCM, heat will be generated inside the cabinet with the help of lamps and the behavior and cooling performance of the PCMs will be compared.

Data Results and Recommendations

In the test results, it is seen that paraffin wax with a low melting point can be produced in the laboratory environment. If the solid and liquid paraffin are mixed in the right amounts, the material can have the desired melting temperature. As a result of the experiment, it is seen that a mixture of 1.5 units of liquid paraffin wax and 1 unit of solid paraffin wax is ideal for the usage scenario in the project. Paraffin waxes produced by industrial PCM manufacturers can also be used in cooling projects under certain conditions. For example, Rubitherm RT35 model can be recommended for server cooling. The use of these paraffin waxes, which have high heat storage capacity and low melting temperatures, are suitable for server cooling. As a result of thermal tests, it is seen that paraffin wax is a suitable material for cooling at the server cabinet level.

Analysis with Ansys

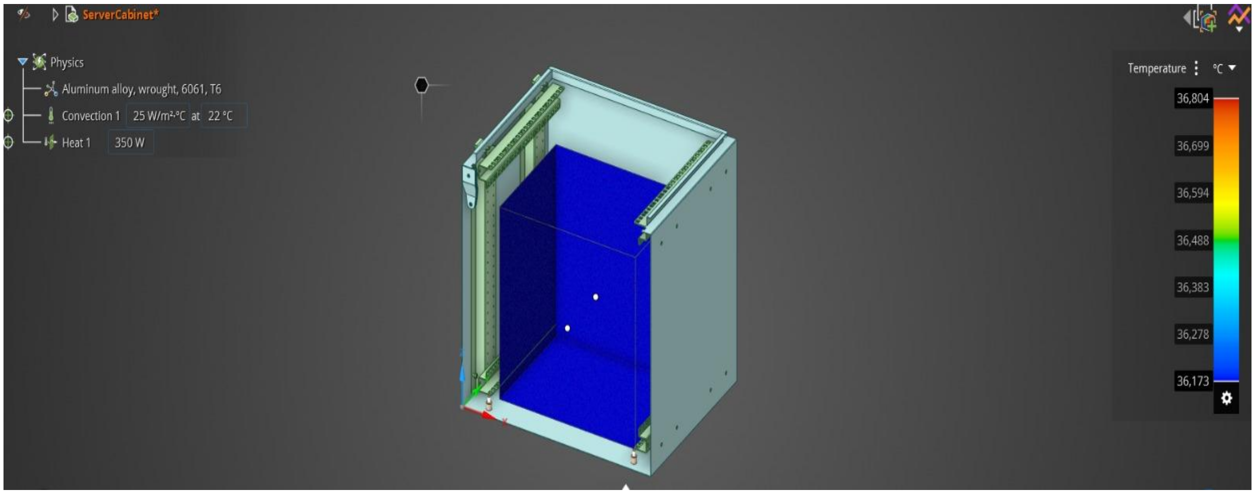


Figure 18. Ansys analysis

This is the heat transfer analysis of the server cabinet while the servers are overworked due to high processing. In this ANSYS Discovery design, the server cabinet's material is chosen as aluminum alloy for testing and convection of 25 W/m2 at 22 °C is applied. Heat generation is happening at 350W.

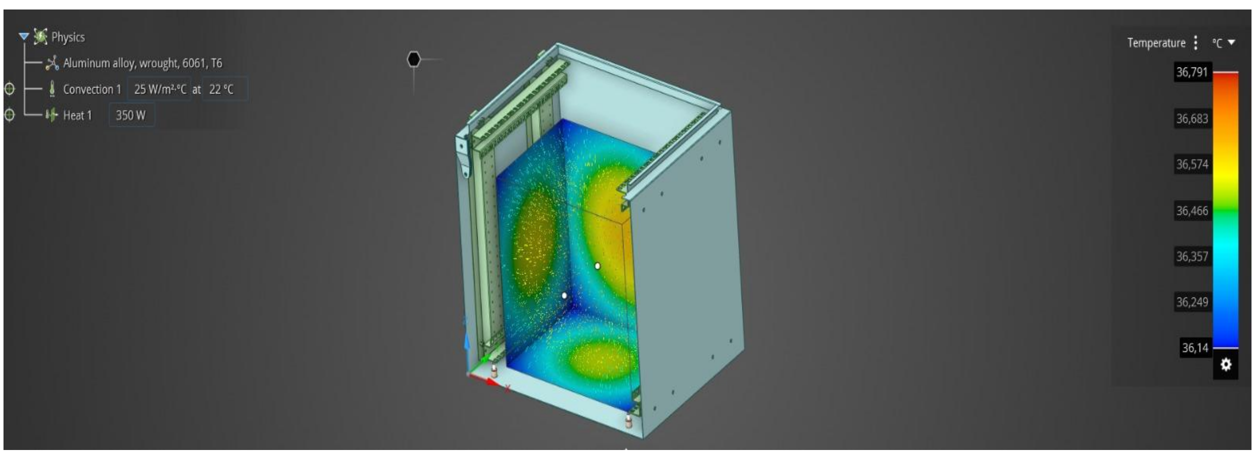


Figure 19. Ansys analysis result

This analysis shows the heat dissipation and also the extreme temperature points. As illustrated here maximum temperature is approximately 36 °C which is very close to machines' maximum operating temperature.

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.

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Resumes

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