

# Load Reduction of HVAC Components by Using PCM

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**Abstract**— This project investigates the use of phase change materials (PCM) as a thermal energy storage system to reduce HVAC load in buildings. PCM absorbs excess heat during temperature periods and release it during cooler period, thereby stabilizing indoor temperature. A 1.5ft × 1.5ft experimental model was developed with or without PCM to analyse thermal performance. The results demonstrate reduce temperature rise and improved energy performance. The result demonstrates reduced temperature rise and improved energy efficiency in PCM - integrated systems. In this study, a scaled experiment model of dimension 1.5ft × 1.5ft × 1.5ft was developed, consisting of two separate chamber one integrated with PCM and the other without PCM for comparative analysis. paraffin wax was selected as the PCM due to its suitable melting temperature range (24-28 °C) chemical stability, and ease of availability. The PCM was incorporated into one wall of the test chamber in a uniformly distributed layer to enhance thermal energy absorption. A controlled heat source was applied to simulate real environment conditions, and temperature variations were recorded using sensors placed inside both chambers. The experiment result demonstrate that the PCM-integrated chamber exhibits a significantly slower temperature rise and lower peak temperature compared to the conventional chamber. This indicates a reduction in heat gain and, consequently, a decrease in HVAC cooling load. effective heat transfer into chamber. The results show a reduction in peak temperature by approximately 5-8°C and a noticeable delay in temperature rise in the PCM-1. The study also highlights the importance of proper system design, including PCM thickness, encapsulation, and the use of high-conductivity materials such as aluminium to enhance heat transfer. Although challenges such as a low thermal conductivity and initial cost exist, the overall benefits in terms of energy savings and environmental impact are significant. In conclusion, the integration of PCM into building components presents a promising and sustainable solution for reducing HVAC load, improving energy efficiency, and enhancing indoor thermal comfort. The proposed system can be further optimized and scaled for real-worlds applications, contributing to the development of green buildings and energy-efficient infrastructure.

**Keywords**—PCM, HVAC, encapsulation, paraffins

## I. INTRODUCTION

The rapid growth in urbanization and industrialization has resulted in a substantial increase in energy consumption, particularly in the building sector. HVAC system accounts for a significant portion of total energy usage in residential, commercial, and industrial buildings. As global temperature rise and the demand for the thermal comfort increases, there is a pressing need to develop innovative solutions that can reduce HVAC energy consumption without compromising indoor comfort. Conventional cooling system operates by continuously removing heat from indoor spaces, leading to high electricity consumption and increased operational costs. *Moreover, peak cooling demand during daytime hours places additional stress on power systems. To address these challenges, researchers have focused on passive and hybrid cooling techniques that can reduce the dependency on active HVAC systems. One such promising solution is the use of latent heat storage through phase change materials (PCM). PCM can absorb, store, and release thermal energy during phase transition, allowing it to maintain indoor temperature within a desired range. Unlike conventional materials that store heat through sensible heat capacity, PCM utilizes latent heat, which enable it to store a significantly large amount of energy without a substantial rise in temperature. When integrated into building components such as walls, ceilings, or HVAC ducts, PCM acts as a thermal buffer. During peak temperature periods, it absorbs excess heat by melting, thereby reducing the rate of temperature increase inside the building. During cooler periods, it releases the*

*stored heat by solidifying, thus maintaining thermal balance. This cyclic process reduces temperature fluctuations, improves thermal comfort, and decreases the operational load on HVAC systems.*

## II. LITERATURE REVIEW

In recent years, the demand for energy-efficient and sustainable building systems has increased significantly due to rising electricity consumption, global warming, and increasing dependence on air-conditioning systems. Buildings consume a large portion of global energy, and a major share of this energy is used by Heating, Ventilation, and Air Conditioning (HVAC) systems to maintain indoor thermal comfort. In residential, commercial, and industrial buildings, HVAC systems are essential for maintaining suitable temperature, humidity, and air quality. However, these systems consume a large amount of electrical power, especially in hot climatic regions where cooling demand remains high for most of the year. The continuous operation of air conditioners increases electricity bills and creates heavy stress on power grids during peak summer periods. In addition, the use of conventional cooling systems contributes to greenhouse gas emissions and environmental pollution. Therefore, researchers and engineers are focusing on passive cooling technologies that can reduce HVAC load without requiring additional electrical energy. Among various passive cooling techniques, the use of Phase

Change Material (PCM) has emerged as one of the most promising solutions. PCM stores thermal energy in the form of latent heat during the process of melting and releases the stored heat during solidification. This unique property allows PCM to maintain nearly constant temperature while storing large amounts of heat, making it highly effective for reducing indoor temperature fluctuations.

The review also reported that proper PCM selection can reduce annual building energy consumption by up to 30–40% and improve occupant thermal comfort substantially. Similarly, S. Dora et al. (2026) reviewed PCM-based thermal energy storage systems for buildings and found that organic PCM such as paraffin wax is the most suitable for residential applications because of its chemical stability, safe handling, and compatibility with indoor thermal conditions. The study explained that PCM is more effective than traditional insulation because it stores heat instead of only resisting heat flow. These studies strongly support the use of paraffin wax in the present project for reducing HVAC load in a small-scale building model.

### III. OBJECTIVE

The primary objective of this project is to investigate the effectiveness of phase change (PCM) in reducing the thermal load on HVAC systems. The study aims to design and develop a small-scale experimental model to analyse the thermal performance of PCM when integrated into building structures. The specific objective is as follows:

- To design a 1.5ft x 1.5ft x 1.5ft experimental model with two chambers for comparative analysis.
- To integrate PCM into one chamber and evaluate its thermal storage capability.
- To measure and compare temperature variation in PCM and non-PCM chambers.
- To analyse the impact of PCM on peak temperature reduction and heat transfer delays,
- To estimate the potential reduction in HVAC cooling load.
- To validate the concept of PCM as a passive energy-saving solution.

### IV. METHODOLOGY

The working principle of PCM is based on PCM is based on phase change heat transfer, where energy is stored and released during the transition between solid and liquid states. During daytime conditions, when the ambient temperature rises, heat enters the building through walls and roof surfaces. The PCM integrated into the structure absorbs through walls and roof surfaces. The PCM integrated into the structure absorbs this heat and begins to melt at its characteristic phase change temperature (typically 24-26 °C for paraffin). During this process, a

large amount of heat absorbs as latent heat without a significant increase in temperature. This phenomenon slows down the rate of temperature rise inside the room, maintaining a more stable indoor environment. As a result, the HVAC system operates less frequently, reducing energy consumption. During nighttime or cooling conditions, the ambient temperature decreases. The PCM releases the stored heat and solidifies, returning to its original state. This cycle repeats continuously, making PCM an effective thermal energy storage medium.

### COMPONENTS USED.

Components are Structural, Thermal and Instrumentation elements. Each element is designed such that accurate thermal analysis is ensured and an efficient demonstration of PCM-based HVAC load reduction can be achieved.

### STRUCTURAL COMPONENTS:

The structural body forms the outer enclosure of the experimental chamber. It is designed to simulate a real building room and provide mechanical support to all internal components. This structural body form is made from the plywood.

- Material used:
  - Plywood board.
  - Thermocol (polystyrene insulation).
  - Adhesive (fevicol/epoxy)
- Function:
  - Provide structural rigidity.
  - Minimize external loss.
  - Support PCM panel and sensor
  - Bear the load of the PCM layer panel.



FIGURE 1 STRUCTURE MADE BY PLYWOOD.

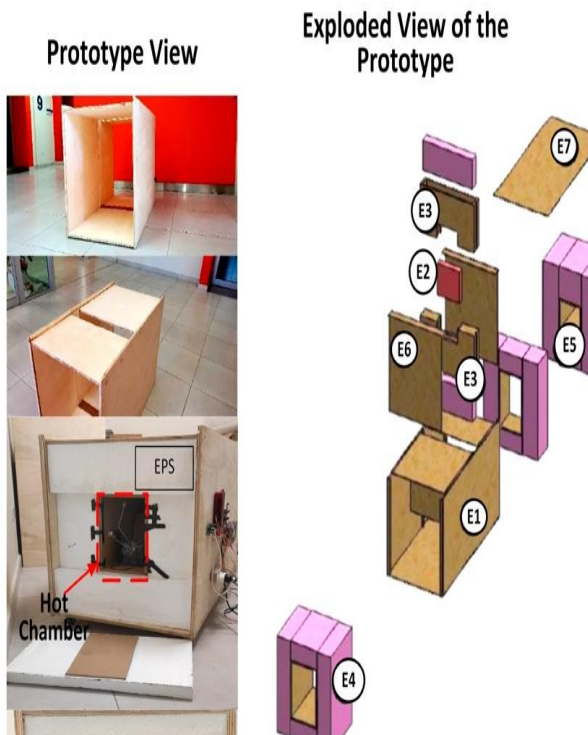


Figure 2. Model and Prototype Overview

**PHASE CHANGE MATERIAL (PCM)**

Phase Change Material is the most important component of the project because it is responsible for thermal energy storage. PCM absorbs and releases heat during phase transition from solid to liquid and from liquid to solid. This process occurs at nearly constant temperature, making PCM highly effective for maintaining indoor thermal comfort.

In this project, paraffin wax was selected as the PCM because of its suitable melting temperature range of 24–26°C, which matches normal indoor comfort conditions. It also has high latent heat storage capacity of approximately 200 kJ/kg, good chemical stability, non-corrosive behaviour, and safe handling characteristics.

When external heat enters the chamber, the PCM absorbs this heat and starts melting. Instead of increasing room temperature quickly, the heat is stored as latent heat inside the PCM. When temperature drops, the PCM releases the stored heat and solidifies again. This cycle repeats continuously and reduces HVAC cooling demand.

- Function: -
  - Absorbs heat during melting.
  - Release heat during solidification.
  - Stabilize indoor temperature.
- Important PCM Properties
  - Melting temperature: 24–26°C
  - Latent heat: ~200 kJ/kg
  - Density: ~900 kg/m<sup>3</sup>
  - Non-toxic and safe
  - Chemically stable
  - Long life cycle performance

*Thermodynamic behaviour.*

➤ *Heat storage mechanism:*

$$Q = ml + mc\Delta T$$

- $ml$ =latent heat.
- $mc\Delta T$ =sensible heat.

*selection criterion for the PCM-material.*

*The Selection of the material depends upon the various factor like melting temperature, latent heat capacity, stability, toxicity and cost also.*

TABLE 1. PCM’S MATERIAL AND THEIR PERPERTIES

S. No	Property	Requirement
1	Melting Temp	24–26°C
2	Latent Heat	24–26°C
3	Stability	High
4	Toxicity	Low
5	Cost	Affordable

➤ Engineering limitation.

- Low thermal conductivity ( $\sim 0.25 \text{ w/mk}$ )
- Solution use of aluminium sheet.

**PCM ENCAPSULATION SYSTEM (CRITICAL DESIGN PART)**

PCM cannot be directly used in open from because it melts into liquid and may leak.

Therefore, it must be encapsulated in containers such as pouches, panels, or metal casings. Encapsulation ensures that the PCM remains in place during phase change and maintains its shape. It also increases the surface area for heat transfer, which improves the efficiency of the system. Proper encapsulation design ensures uniform heat absorption and prevents material degradation. Flat and thin encapsulation is preferred for better performance.

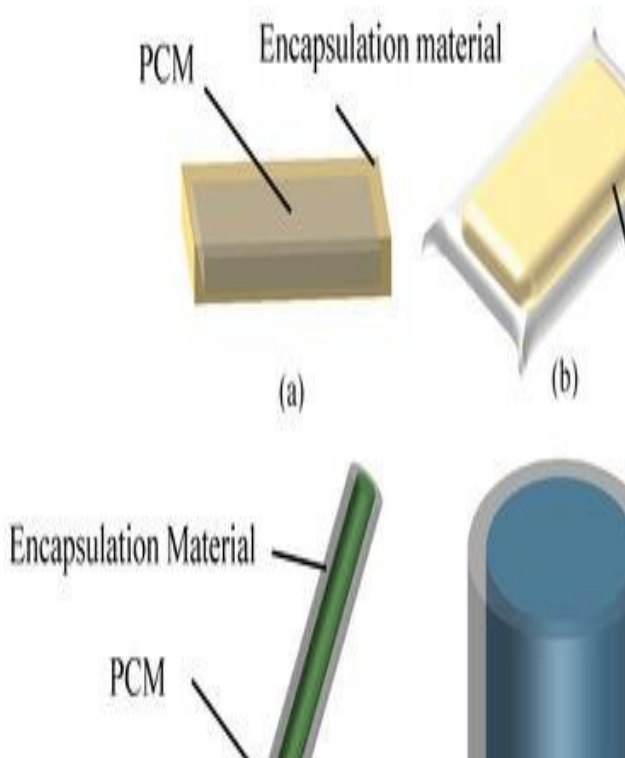


FIGURE 3. ENCAPSULATION MADE FOR THE PCM.

- Why encapsulation is required:
  - It prevents leakage during melting.
  - Maintain shape.
  - Improve surface contact.
- Type of encapsulation can be used for this type of application.

TABLE 2. ADVANTAGE OF USING DIFFERENT TYPE OF ENCAPSULATION MATERIALS.

Type	Use	Advantage	
Macro	Panels/pouches	Easy fabrication	would loss heat, reducing the effectiveness of the PCM.
Micro	Mixed in walls	Uniform distribution	reducing the effectiveness of the PCM.
Shape-stabilized	Polymer mix	No leakage	

- Design specification of the encapsulation for PCM-materials.
  - Thickness:10mm.
  - Must be uniformly distributed.
  - Avoids air gaps.
  - Can be plastic pouch or aluminium casing.
  - Prevents leakage during melting.
- Heat transfer role of the encapsulation for the PCM-material.
  - Large surface area→ better heat absorption.
  - Flat geometry →uniform melting.

**ALUMINIUM SHEET (THERMAL ENHANCEMENT LAYER)**

Aluminium act as a heat spreader. Aluminium sheet is used as thermal enhancement layer between the PCM and the inner chamber. Since the PCM has low thermal conductivity, it cannot absorb heat efficiency on its own. Aluminium, being a highly conductive material, helps in distributing heat evenly across the PCM surface. This ensures that the entire PCM layer participates in the phase change process. It also reduces thermal resistance and improves the overall efficiency of the system. The use of aluminium significantly enhances the response time of the PCM.

- Why needed.
  - PCM conductivity: - ( $\sim 0.26 \text{ w/mk}$ ) (very low).
  - Aluminium conductivity: - ( $\sim 205 \text{ w/mk}$ ) (very high).
- Function:
  - distributes heat evenly.
  - Reduces thermal resistance.
  - Speeds up melting process.
  - Improves heat transfer rate.
  - Essential for efficient PCM usage.
- Placement: -
  - Between PCM and inner chamber.
  - Thickness: - 0.5-1mm.

**INSULATION MATERIAL.**

Insulation is used to minimize head loss to the surroundings and ensure that heat flows through the intended path, i.e., through the PCM layer. It plays a critical role in maintaining the accuracy of the experiment by preventing unwanted heat exchange. Material like thermocol (expanded polystyrene) are commonly used due to their low thermal conductivity. Proper insulation ensures that the thermal energy is effectively stored and utilized by the PCM. Without insulation, the system

- Thermal role:
  - Reduce heat loss.
  - Improves experimental accuracy.
  - Maintains temperature gradient.
  - Reduces heat loss to environment.
  - Must cover all outer surface

- Material properties:
  - Thermal conductivity ( $\sim 0.03 \text{ w/mk}$ )
  - Thickness: - 5-10 mm.
- Placement: -
  - Outer walls.
  - Behind PCM layer.

**Heat source.**

The heat source is used to simulate real environmental conditions such as solar radiation or ambient heat. It provides a controlled and consistent heat input tom both chamber of the model. This allows for a comparison between PCM and non-PCM systems. The heat source typically consists of an electric bulb or infrared lamp

placed at a fixed distance from the model. Proper positioning is important to ensure uniform heat distribution across the chamber surfaces.

- Heat transfer modes:
  - Radiation (primary).
  - Convection (secondary).
- Setup parameters:
  - If we setup the lamp it should be 10-15cm from model.
  - Power: - 60 -100w bulb.
  - Simulate solar heat load.
  - Provides controlled heating conditions.

### TEMPERATURE SENSORS.

Temperature sensors are used to measure the temperature inside the chambers during the experiment. They provide real-time data that helps in analyzing the thermal performance of the PCM. Sensors such as LM35 and DS18B20 are commonly used due to their accuracy and ease of integration. Proper placement of sensors is essential to obtain reliable data. The sensors help in comparing temperature variations and validating the effectiveness of PCM.

- Working principle:
  - LM35 →voltage proportional to temperature.
  - DS18B20 →digital output.
- Key points: -
  - Measure temperature variation.
  - Provides real-time data.
  - Placed at center and near PCM wall.
  - Accuracy is critical.
  - Used for performance comparison.

### V. DESIGN CALCULATION

The design calculations are essential to determine the required quantity of PCM and its heat storage capacity. The volume of PCM is calculated based on the area of the wall and thickness of the PCM layer. Using a wall area of  $0.209m^2$  and a thickness of 0.01m, the volume is obtained as  $0.00209m^3$ .

The mass of PCM is determined using its density ( $900 kg/m^3$ ), resulting in approximately 1.88kg. For practical implementation, a slightly higher value of 2-2.2 kg is recommended to account for losses and non-uniform distribution.

The heat storage capacity is calculated using the latent heat of fusion of paraffin (~ 200 kJ/kg), yielding a total storage capacity of approximately 376kJ. This represents the amount of heat that can be absorbed without increasing temperature, directly contributing to HVAC load reduction.

- Given data,
  - Chamber size=  $1.5ft \times 1.5ft \times 1.5ft$ .
  - 1 ft=0.3048m
  - 1.5 = 0.4572m.
  - PCM Thickness (t) = 10mm=0.1 m
  - Density of paraffin (900kg/)

- Latent heat (l)=  $200kJ/kgm^3$
- Specific heat(cp)~ $2kJ/kg$
- Area calculation.
  - Area of one wall: -  $A = L \times W$

$$A = 0.4572 \times 0.4572 = 0.209m^2$$

#### ➤ Volume of PCM.

$$V = A \times t$$

$$V = 0.209 \times 0.01 = 0.00209m^3$$

#### ➤ Mass of PCM

$$m = \rho \times V$$

$$m = 900 \times 0.00209 = 1.89kg.$$

#### ➤ Sensible heat storage.

$$Q_{sensible} = m \times cp \times \Delta T$$

- Assume:  $\Delta T = 10$

$$Q = 1.88 \times 2 \times 10 = 37.6kJ$$

#### ➤ Heat storage capacity. (latent heat).

$$Q_{latent} = m \times L$$

$$Q = 1.88 \times 200 = 376kJ$$

#### ➤ Total heat storage.

$$Q_{total} = Q_{latent} + Q_{sensible}.$$

$$Q_{total} = 376 + 37.6 = 413.6kJ$$

#### ➤ Interpretation.

- PCM absorbs 413kJ heat.
- Major part = latent heat (~90%).

#### ➤ Heat transfer through wall (without PCM)

- By, using conduction equation:

$$Q = \frac{KA\Delta T}{x}$$

Where:

- $k = \text{thermal conductivity.}$
- $A = \text{area of the wall.}$
- $\Delta t = \text{temperature difference.}$
- $x = \text{thickness of the wall.}$

Assume:

- $k(\text{wall}) = 0.5w/m^2$
- $\Delta T = 15^\circ C$
- $x = 0.01m$

$$Q = \frac{0.5 \times 0.209 \times 15}{0.01} = 156.75w$$

#### ➤ Heat transfer with PCM

$$Q_{effective} = Q_{input} + Q_{stored}.$$

- Heat input from wall:

$$Q_{input} = 156.75w$$

- Total heat stored:

$$Q_{stored} = 413.6kJ$$

$$Q_{stored} = \frac{413.6 \times 1000}{3600} = 114.88w$$

- Effective heat entering chamber:

$$Q_{\text{effective}} = Q_{\text{inout}} + Q_{\text{stored}} .$$

$$Q_{\text{effective}} = 156.75 - 114.88w = 41.87w$$

- Heat entering chamber with PCM=  
 $\approx 41.87w$

➤ Temperature reduction:

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc}$$

$$\Delta T = \frac{156.75}{1.88 \times 2} \approx 6 - 7^\circ\text{C}$$

➤ Heat reduction %;

$$\text{reduction} = 157 - 42 = 115w$$

$$\% \text{reduction} = \frac{115}{157} \times 100 \approx 73\%$$

## VI. RESULT.

The experimental result indicates a clear difference in thermal performance between the PCM-integrated chamber 1 and without PCM chamber 2.

The chamber without PCM shows a rapid increase in temperature due to direct heat transfer. In contrast exhibits or sustain with slower temperature rise, as a significant portion of heat is absorbed during the phase change process.

The peak temperature in the PCM chamber is observed to be lower by temperature  $5-8^\circ\text{C}$  as compared to the non-PCM chamber. Additionally, the rate of temperature increase is reduced, indicating delayed heat transfer. These results confirm that PCM effect

## VII. DISCUSSION

The result obtained from the experiment validate the effectiveness of PCM in thermal energy storage and HVAC load reduction.

The presence of PCM introduces a thermal buffering effect, which reduces temperature fluctuations and delays heat transfer. This directly impacts the performance of HVAC system by reducing the frequency of operation and energy consumption.

The efficiency of the system depends on factor such PCM selection, thickness, placement, and environmental condition. Proper design optimization are essential to achieve maximum benefits.

The result also indicates a delay in peak temperature occurrence, known as thermal lag, which is highly beneficial in reducing peak load demand during daytime. This delay allows HVAC system to operate under less stressful conditions, improving efficiency and lifespan.

However, the performance of PCM is influenced by several factors such as:

- Proper selection of melting temperature.

- Uniform distribution of PCM.
- Adequate insulation.
- Environmental conditions.

Overall, the discussion confirms that PCM act as an effective thermal buffer, reducing temperature fluctuations and improving energy efficiency.

**ADVANTAGES:**The integration of PCM into building systems provides multiple technical and environmental benefits:

- Energy efficiency.

PCM significantly reduces the cooling load HVAC systems by absorbing excess heat. This leads to lower electricity consumption and improved energy efficiency.

- Peak load reduction.

PCM stores heat during peak hours, reducing the demands on cooling systems. this helps in minimizing peak electricity usage and reduces strain on power grids. ref

- Improve the thermal comfort.

By maintaining a stable indoor temperature, PCM enhances occupant comfort and reduces temperature fluctuations.

- Passive cooling system.

PCM operate without any external energy input, making it a passive and sustainable cooling solution.

- Environmental benefits.

Reduced energy consumption leads to lower greenhouse gas emission, contributing to eco-friendly building design.

- Compact thermal storage.

PCM provides high energy storage capacity in a small volume due to latent heat storage, making it suitable for compact systems.

**LIMITATION:** Despite its advantages, PCM systems have certain limitations that must be considered:

- High initial cost.
- Low thermal conductivity.
- Material degradation.
- Leakage issue.
- Design complexity.
- Limited temperature range.

**APPLICATIONS:**PCM technology has wide applications across different engineering and industrial fields:

- Building construction.

- Used in walls, callings, and floors for thermal regulation.
- Helps in developing energy-efficient buildings.

- HVAC systems.

- Integrated into air ducts for pre-cooling.
- Reduces load on air conditioning systems.

- Solar energy systems.
    - Stores solar thermal energy for later use.
    - Improves efficiency of solar heating systems.
  - Cold storage & refrigeration.
    - Maintains temperature in storage units.
    - Reduces compressor usage.
  - Automotive industry.
    - Used in vehicle cabins to regulate temperature.
- Improves passenger comfort.
- Electronics cooling.
    - Used in cooling of electronic devices and batteries.
    - Prevents overheating.

## VIII. 15.CONCLUSION.

This projects successfully demonstrates the application of phase change materials in reducing HVAC load through thermal energy storage. The experimental results clearly indicate that PCM integration leads to a significant reduction in temperature rise and peak heat load inside the chamber. The ability of PCM to absorb and release large amounts of heat during phase change make it an effective solution for thermal management. The system not only improves energy efficiency but also enhances indoor comforts by maintaining a stable temperature. The calculated heat storage capacity is  $413.5\text{ kJ}$  and observed temperature reduction ( $\sim 5 - 8^\circ\text{C}$ ) confirm the effectiveness of the proposed design. The study highlights that PCM can serve as a thermal energy buffer, reducing the dependency on HVAC systems. In conclusion, PCM-based systems offer a promising approach for suitable building design and energy conservation, especially in regions with high cooling demand.

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