

Analysis of Latent Thermal Energy Storage using PCM for HVAC Building of Multan-Pakistan

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Abstract. Pakistan's residential sector is a large energy consumer. To naturally generate comfortable living environments, architectural design features must react to changing situations. The current study is intended to examine the Cooling load and energy performance enhancement of residential buildings by integrating Phase Change Materials (PCM) in the building envelopes for the Climate of Multan, Pakistan. When incorporated into a building's structure, phase change materials (PCMs) act as an efficient thermal mass, potentially lowering ongoing building operation costs such as those associated with daily heating and cooling. This study examined the Passive design of HVAC Building through insulating Material, Phase change material and Climatic Consultant Software. The Analysis using the PCMs in the building envelope prioritized materials are A25H, A22H, Croda Therm21 and S540 for energy performance of Multan-Pakistan Region. Using PCM (Croda Therm21, A25H, or A22H) with the thickness of 10mm in the walls results in an approximate energy savings of 19.51% compared to not using PCM. Using SP50 PCM on the outer wall of the building to improve energy efficiency in residential structures is cost-effective in Multan because SP50 with a thickness of 50mm melting temperature of 50 to 51 degree Celsius bio based phase change material it offers a high latent heat capacity and biodegradable. Climate Consultant Software Identified the Passive design techniques, including natural ventilation, daylight utilization, landscaping, sustainable materials, orientation, and shading systems, optimize energy flow for thermal comfort in buildings, tailored for specific climates like the hot and dry region of Multan, Pakistan, meeting ASHRAE Standard 2005 for indoor comfort without artificial support.

Keywords: Phase change Material, Overall Heat transfer coefficient, Thermal Storage of Energy. Climate Consultant.

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1. Introduction

Pakistan is seeing the highest rate of urban population growth in South Asia, with an annual growth rate of 3%. Nearly half of Pakistan's population is expected to live in cities by 2025. (Kugelman et al.,2013). Before creating building rules and bylaws, a thorough examination of local materials, construction methods, and housing requirements in regard to ASHRAE standard 90.2 is required. HVAC aims to ensure human comfort and satisfaction with the thermal environment,

as stated in the ASHRAE Standard. However, it emphasizes that comfort judgment is a cognitive process impacted by physical, physiological, psychological, and other factors. The demand for cooling is increasing due to economic expansion, growing urbanization, rising global temperatures, and frequent heat waves. Increased cooling causes more climate change necessitates additional cooling measures. Urgent action is required to interrupt the negative feedback loop. In 2018, Pakistan contributed for 0.7 percent of total world air

conditioning utilization, with an estimated 824,000 units out of 111 million all over the world. Researchers believe that the country has the fifth-highest potential demand for air conditioning. One of Pakistan's difficulties is outdated technology. Before 2010, a Working fluid (refrigerant) known as Dichlorofluoromethane, or Chlorodifluoromethane (CHClF₂), Freon, was exploited in cooling methods around the world, but it was discovered to be extremely harmful to the ozone layer (OL). In response, countries such as the United States initiated planning to replace it (Energy-Efficiency: A Guidebook, 2021). New energy development and industrial waste heat recovery are crucial in addressing the pressing issues of energy crisis and pollution. New energy sources like solar and wind, as well as waste heat in traditional businesses, are sometimes unreliable and unpredictable. Thus, thermal energy storage (TES) has been a critical technology in ensuring that new energy and industrial WHRS operate efficiently and reliably. Over the past few decades, scientists have focused on researching high-efficiency TES devices. Phase change material collecting the energy from environment then convert solid to liquid. Higher energy values are found in the energy storage during phase change than in the specific heat capacity during "normal" heating of the substance in question. Because of this, there is a benefit in terms of energy storage density, particularly for little temperature variations. Sensible heat, another name for the specific heat that results from "normal" heating, is linked to an increase in temperature. With regard to latent (hidden) heat, this is untrue.

2. Literature Review

Energy consumption in Pakistan's building industry accounts for over 30% of total energy consumption and is growing at an annual pace of 4.7% and 2.5% in the household and commercial sectors, respectively

(Khurshid Ahmad et al., 2014). HVAC not only consumes huge amount of energy but also causes environmental degradation (Zeng et al., 2011).

The Pakistani National Energy Conservation Centre (ENERCON) has set a target of reducing household energy use by 30%. The policy also provides specific recommendations for coordinating with the provincial governments and regions, as well as the enforcement mechanisms necessary for the adoption and compliance of EE&C regulatory measures, based on techno-economic analysis. (Zhao Y et al., 2016). In this research paper the housing Paradigm shifted into Housing, Thermal Comfort, and Energy Efficiency and Renewable energy. (Mahar et al., 2019). The NEECA replaced the ENERCON in 2016. It is in charge of:

- Creating programs for energy saving in key energy sectors. Creating plans for energy conservation. Creating policy directives to assist energy-saving.

Creating a database on potential energy-saving opportunities; planning and facilitating training sessions and workshops; conducting fieldwork and experimentation; and putting energy-saving initiatives into action and keeping an eye on them (BCP-EP (2011). In order to evaluate the thermal behavior and characteristics of one of the very special components used as a figurative eminent element of the building envelope, as well as its thermal behavior under the influence of solar temperatures and its role in heat exchange related to a specific U-value of specified construction material alternatives, the current paper will be conducted. The new mosque in Baghdad, Iraq, and the stipulated hot, dry weather will be used as a case study in the research methodology. Additionally, information about design parameters and thermal assessment for a "model dome" will be provided in relation to the requirements of indoor thermal comfort. (Hwaish et al., 2018). Pakistan announced that it is

taking the first steps in this direction. In 2021, it declared in its updated NDC that it will implement a Pakistan Cooling Action Plan (PCAP) by 2026. It will identify the key cooling needs and priorities actions for addressing current and future cooling demands with the minimum possible impact on the environment (Pakistan Cooling Action Plan, 2021). LHS has been used successfully in solar thermal utilization, industrial waste heat recovery, building energy savings, electronics cooling, and more. With the use of LHS, various studies on the performance of PCMs and LHS systems have been conducted. This paper will provide a comparative review of various PCM types, enhancing methods, and attributes. This will help in selecting dependable PCM and a method for improving the thermal performance of a PCM-based LHS system. This paper will examine research gaps in performance enhancement strategies for LHT systems and give recommendations for further study. (Sharma A. et al., 2009) Porous material absorbs PCM, resulting in CPCM. Porous media with high thermal conductivity and porosity can effectively improve PCM thermal conductivity. Used an enough PCM to maintain a high energy storage density like Metal foams include copper (Liu Z et al., 2013; Xiao X et al., 2014; Zhao Y et al., 2016), nickel (Tao YB et al., 2016; Zhao Y et al., 2016; Liang W 2015), and aluminum (Wang Z et al., 2015). As a result, PCMs can play a vital role in building envelopes, transferring

building loads during peak hours. Reducing energy usage for cooling and heating systems while improving occupant comfort. (Tyagi et al., 2007). Karachi, Pakistan's largest city, experiences a warm desert climate, making it one of the country's dominant climates. This city is located in the northern hemisphere, along the Indian Ocean shoreline. The hottest month is June, with maximum daily temperatures above 32 °C, while the coldest month is January, with lowest temperatures below 5 °C. It experiences rain in both summer and winter, with a higher concentration in winter. It experiences both sea and land winds throughout the year. (Owen et al., 2009) examined the uses of PCMs for heating, cooling, and energy generation on four temperature scales (Du et al., 2018) Classify melting temperatures based on the desired application. However, the cheapest and widely available (Han et al., 2017) Total heating and cooling usage in Quetta can be reduced by 49.6% on a monthly average; in Islamabad, it can be reduced by 44.9%; in Karachi and Peshawar, it can be reduced by around 35%; and in Lahore, it can be reduced by 32%. Additionally, by using appropriate PCM in the building envelope, multiple zone two-story residences in Karachi, Lahore, Quetta, Peshawar, and Islamabad can achieve energy reductions of 21.4%, 15.5%, 13.5%, 12.9%, and 12%, respectively (Khan et al., 2022).

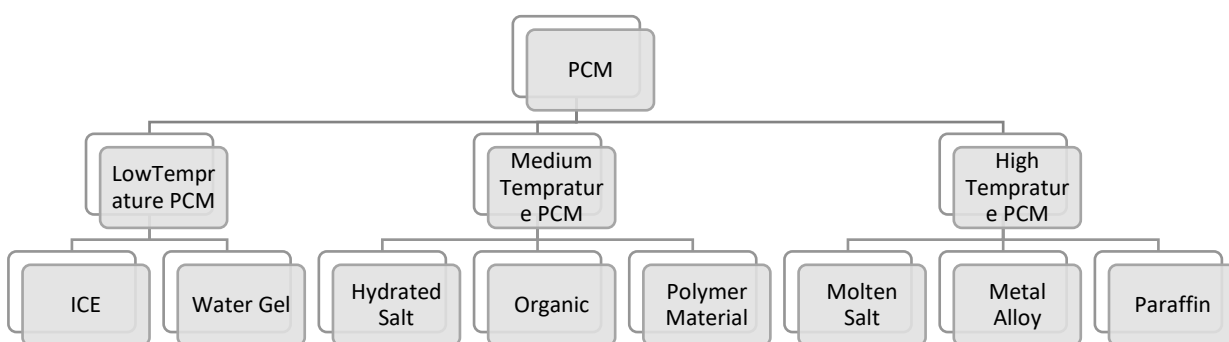


Fig.1 Categories of PCM based on melting Point H. Ge et al. (2018)[21]

3. Research Objectives

- Analysis prevailing the climatic condition Best Design Strategies of Selected Region by using data from psychometric charts ASHRE Standard (Climate Consultant Software).
- Evaluating the Heat gains values with or without using the PCM type and thickness variation and Insulating Materials.
- Analysis the Energy Consumption and Economic Analysis.

4. Climate Zone of Multan Pakistan Hot and Dry Region

Pakistan is located in a diverse geographical features temperate zone, with a temperature that varies as much as the geography of the region. It is often hot and dry near the coast and along the Indus River's lowland plains, and it gets gradually colder in the Himalayas and northern uplands. Pakistan climate is tropical, with high temperatures predominating there. As seen in Fig 1.

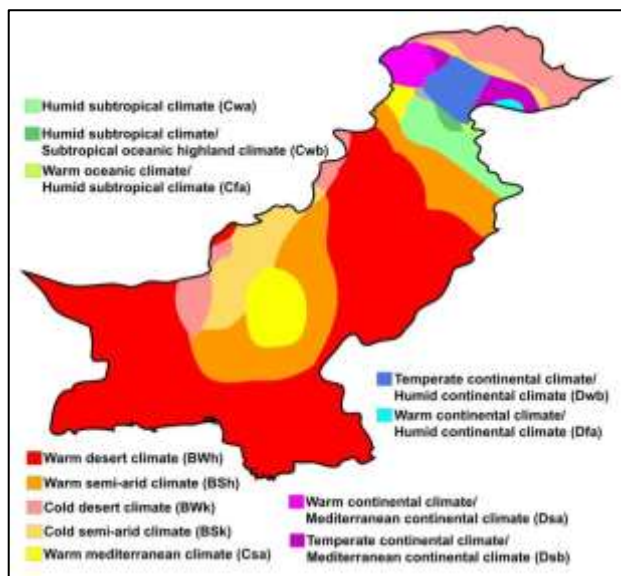


Fig:-1 Climate Classification of Pakistan
@en.wikipedia.com

5. Selected Site for Passive Design of Building

This research is based on a solution for Sustainability and optimization of a building in Multan, Pakistan. Multan's latitude and longitude (30.292267 and 71.49887) indicate that the city experiences a sunny and hot environment throughout the year. Analyzing passive

design for a building in Multan, Pakistan, requires taking into account the local climate, available resources, and cultural preferences. Multan has a hot desert environment, with extremely high summer temperatures and comparatively mild winters. In Fig 2 graphical behavior of the temperature profile in Multan, with maximum temperatures reaching 45 degrees Celsius, is crucial for designing buildings with effective passive cooling strategies. Here's a breakdown of how such temperatures might influence passive design considerations over the course of a year:

During the summer months, when temperatures surge to their greatest levels, passive cooling is essential.

- To prevent direct sunlight from entering the building, use shading devices such as big overhangs, awnings, or exterior blinds.
- Natural ventilation becomes crucial during this time, with precise window design to allow for cross-ventilation and airflow throughout the building.
- HTM materials can absorb heat throughout the day and slowly release it at night, thereby stabilizing indoor temperatures.

By adjusting passive design solutions to Multan's specific temperature conditions, buildings can achieve year-round thermal comfort while reducing reliance on mechanical cooling and heating systems.

6. Understanding Building Characteristics

Location and Climate: Determine the building's location and climate zone, as these have a substantial impact on heating and cooling requirements.

- **Building Design:** Examine the building's orientation, window-to-wall ratio, shading devices, and natural ventilation capacity.
- **Insulation:** Types of insulation: Determine the best insulation materials (e.g., fiber glass, foam board, spray foam) based on thermal resistance (R-value), cost, and suitability. To reduce energy consumption and cooling load, passive and zero energy buildings

incorporate a variety of energy-efficient solutions, such as high-performance insulation and phase change materials (PCMs).

7. Thermal Comfort Key issues

Most of us live in inefficient homes with active cooling and heating systems. A building must provide a comfortable internal environment while being energy efficient. As per the standard Building Code of Pakistan (BCP), 21 degrees Celsius in summer and 26 degrees Celsius in winter for HVAC System, regardless of the location of the building across the country.

8. Comfort Strategies for Climatic Zones by Climate Consultant

Passive design techniques to energy-saving strategies used in buildings to achieve thermal comfort in specific

climates. Passive techniques can significantly improve thermal comfort (Tanya Ha and J. B., 2008). The Comfortable design uses numerous passive tactics such as natural ventilation. To optimize energy flow within a building, consider day light use, landscaping, sustainable materials, orientation design, and various shading systems. The data evaluated for Hot and Dry Climate Region for specific city Multan Pakistan observed through climate consultant software. According to ASHRE Standard -2005 in fig.3 Building design must regulate natural conditions to make indoor spaces agreeable without the need for artificial support, with 14.1% falling within the human comfort zone. Low water content in the air, extreme heat, and intense sun radiation must all be considered in design.

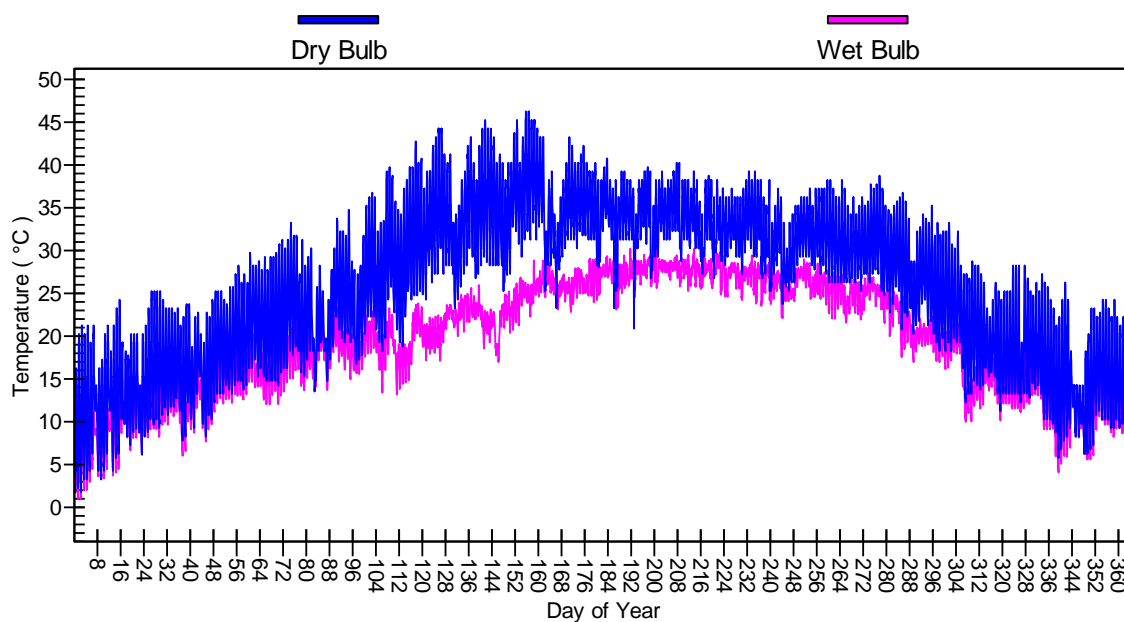


Fig. 2. Temperature Profiles of Multan (January to December) @HAP Software

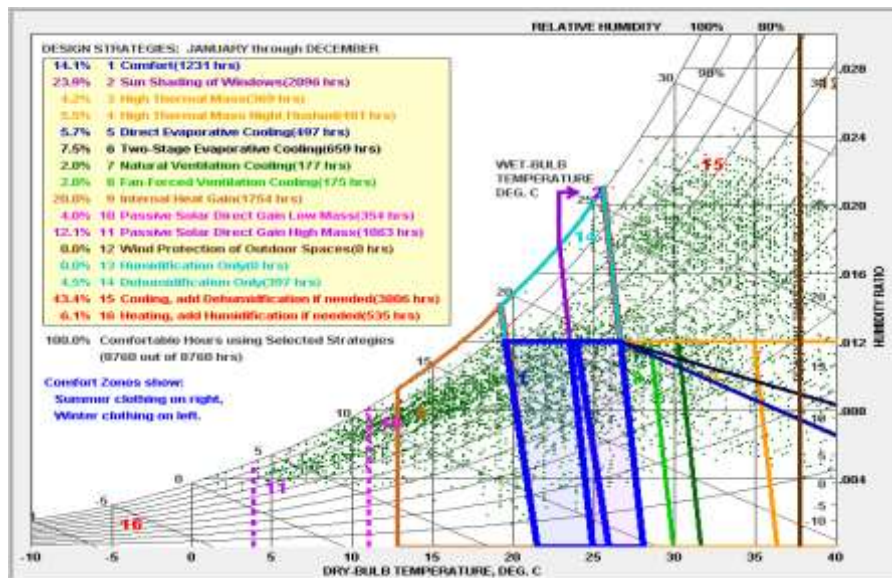


Fig. 3. Design Strategies ASHRE Standard 2005

The Analysis is to maximize comfort in naturally ventilated buildings through passive heating and cooling design solutions. In Multan, Pakistan, passive cooling and heating tactics that include natural ventilation, solar shade, and internal heat gains lead to more comfortable hours.

In this research study examined the easily available PCM Rubi-Therm different phase change materials which have low and high melting temperature ranges between -20 to 100 degree Celsius used for the Hot and Dry Desert climate condition of Multan Pakistan. The Properties of thermos-physical are mentioned in Table 1.

Table:-1 Properties of Phase Change Material (RubiTherm.Co)

Material	SP2 1EK	SP2 4E	SP2 5E2	A2 2H	A2 5H	RT2 1HC	RT2 2HC	RT2 5HC	PureTe mp18	PureTe mp20	PureTe mp23	CrodaTh erm19	CrodaTh erm21	CrodaTh erm24W	CrodaTh erm24	SP 50
Melting Temperature	22	24	25	22	25	21	22	25	18	20	23	19	21	23	24	50
Freezing Temperature	21	23	24	22	25	20	21	23	18	20	23	18	20	23	21	35

9. Building Characteristic

The light commercial residential building in Multan have mentioned building characteristic the summer inside design temperature is 65°F and outside design conditions are 113°F, 36% Relative humidity. The 8 in. concrete floor is a slab-on-grade with R = 5.4 insulation, No of occupants 5 Lights 2000 Watts properly installed.

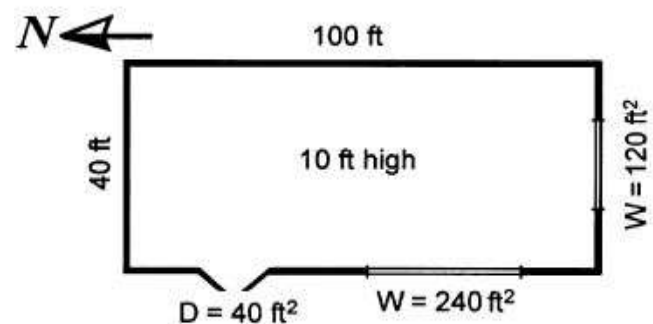


Fig.4 Residential building Area

10. Heat Gains and Cooling Load Calculation

The conduction rate equation, Fourier's law applied on it for calculation the Heat gain through Construction's

Material. Given that heat flow is a vector quantity, the conduction rate equation (Fourier law) can be expressed in 1,2 & 3.and multilayer wall conduction convection phenomenon explains in eq 4. Wall Characteristic of Material Mentioned in fig.5 & Table 2.

$$q'' = -k \cdot dt/dx \tag{1}$$

$$q'' = -k \Delta T = \left(i \frac{\partial T}{\partial x} + y \frac{\partial T}{\partial x} + z \frac{\partial T}{\partial x} \right) \tag{2}$$

$$k = \left(- \frac{q''}{\left(i \frac{\partial T}{\partial x} + y \frac{\partial T}{\partial x} + z \frac{\partial T}{\partial x} \right)} \right) \tag{3}$$

$$qx = \frac{T_{\infty 1} - T_{\infty 4}}{\left[\left(\frac{1}{h_{1A}} + \frac{L_1}{k_{1A}} + \frac{L_2}{k_{2A}} + \frac{L_3}{k_{3A}} + \frac{1}{h_{2A}} \right) \right]} \tag{4}$$

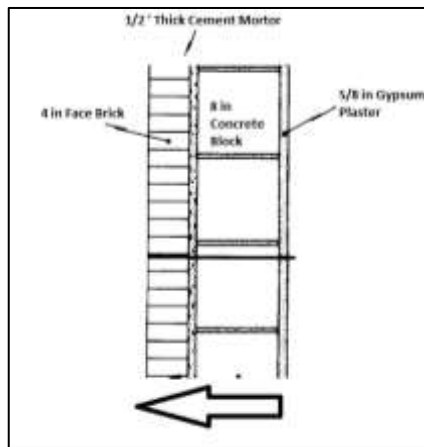


Table: 2. Building Material Overall Heat Transfer Coefficients

Name	Constructions (Outside to Inside)	Overall Heat Transfer Coefficient (Btu/h·ft ² ·°F)
Wall	Inside Air Film, Gypsum Plaster, 8 in Hollow Concrete Block, Cement Mortar, Face Brick, Inside Air Film	U = 0.346 Btu/h·ft ² ·°F
Roof	Plaster, Bitumen, RCC Slab, Plaster	U = 0.12 Btu/h·ft ² ·°F
Floor	Cement Mortar, Concrete, Aggregate, Sand, Earth/Soil	U = 0.42 Btu/h·ft ² ·°F
Window	1/8 inch. regular sheet	U = 1.30 Btu/h·ft ² ·°F
Door	2 in. solid wood	U = 0.42 Btu/h·ft ² ·°F

Table: 3. Total Heat Gain of Residential Building without PCM

Construction Element	U (Btu/h·ft ² ·°F)	A (m ²)	ΔT (F)	Q (Btu/h)
East Wall	0.346	1000	66	23100
North Wall	0.35	400	66	9240
West Wall	0.35	720	66	16632

Fig: 5. Building Wall Thermal Resistance

Total building load executed in table 4 without insulation more cooling load and more energy consumption. It is essential to comprehend the connection between energy consumption and cooling load when utilizing Phase Change Materials (PCMs) and insulation materials to calculate the heat load for buildings. By slowing down the pace at which heat moves through the building envelope, PCMs and insulation materials are intended to improve a structure's thermal performance. However, according on their thermal characteristics, such as thermal resistance and conductivity, their efficacy might differ greatly. Higher energy consumption is usually a sign that more energy is needed to maintain the ideal internal temperature in those buildings.

South Wall	0.35	280	66	6468
Door	0.42	40	66	1108.8
South Glass	1.3	120	66	10296
West Glass	1.3	240	66	20592
Floor	0.12	4000	66	31680
Roof	0.49	280	66	9055.2

$$q_{sensible} = 1.01Q(ti - to) \quad (5)$$

$$q_{latent} = 4840Q(Wi - Wo) \quad (6)$$

Where at ACH=0.5

$$Q = 0.5 \cdot (40 \times 100 \times 10) / 60 = 333$$

Thus,

$$q_{sensible} = 1.01 \times 33 \times 66 = 24200 \text{ Btu/h}$$

$$q_{latent} = 4840 \times 333 \cdot (0.005 - 0.001) \text{ Btu/h} = 6447 \text{ Btu/h}$$

$$\text{Total Design Load} = 159152$$

Table: 4. Total Heat Load of Building with Building without Insulation Material

Material	Resistance Of Building Wall (Rtotal) h·ft ² ·°F/Btu	Overall Heat Transfer Coefficient of Wall. (U) Btu/h·ft ² ·°F	Overall Heat Transfer Coefficient. (Ut) Btu/h·ft ² ·°F	Heat Load (Q total) Btu/h	Cooling Load (Tons)	Energy Consumption (Kwh)
Without Insulation	2.8978	0.3451	5.0104	159152	13.26267 Approx. 14 Ton	711.18

Table:-5 Total Heat Load of Building with Building Insulation Material

Material	Thermal Conductivity (K) (BTU/(h.ft.F)	Resistance Of Building Wall (Rtotal) h·ft ² ·°F/Btu	Overall Heat Transfer Coefficient of Wall (U) Btu/h·ft ² ·°F	Overall Heat Transfer Coefficient (Ut) Btu/h·ft ² ·°F	Heat Load (Q total) Btu/h	Cooling Load In Tonnage	Energy Consumption (KWh)
Expanded Polystyrene	0.0225	20.6251	0.0485	3.8239	111060	9.255	499.77
Extruded polystyrene	0.02137	21.1477	0.0473	3.8191	110870	9.239166667	498.915
Fiber Glass	0.02484	18.5983	0.538	3.8454	111900	9.325	503.55
Polyurethane Foam	0.021	21.4692	0.0466	3.8163	110760	9.23	498.42

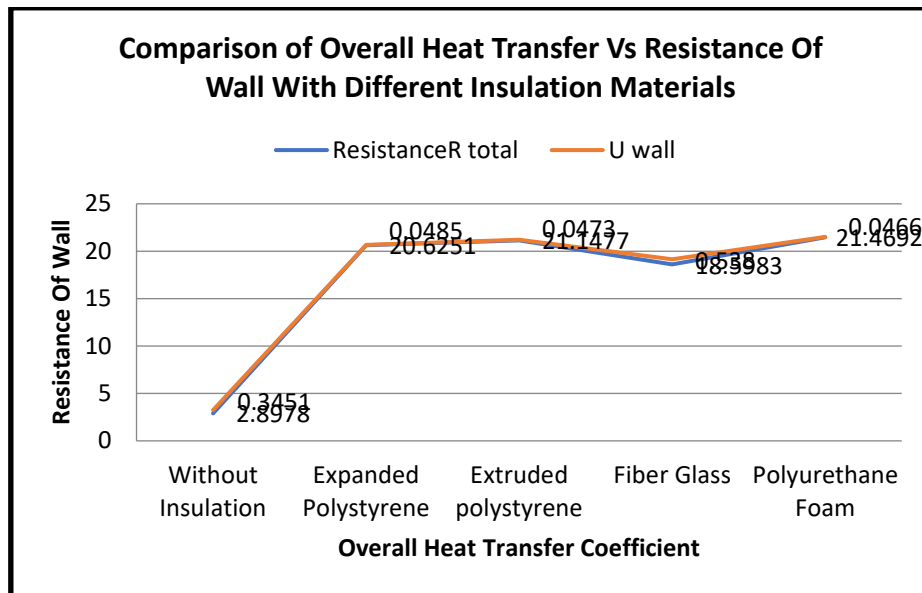


Fig: 6. Comparison of Overall Heat Transfer vs. Resistance of Wall with Different Insulation Materials

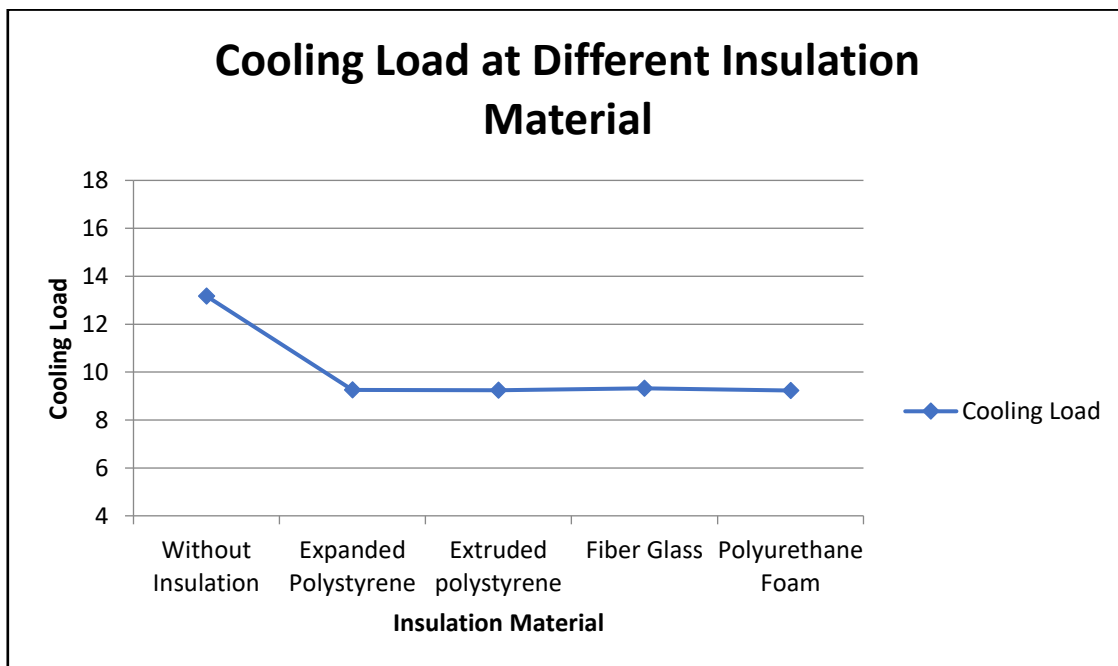


Fig: 7. Cooling versus Energy Consumption

The four materials examined in Table 5, polyurethane foam has the lowest cooling load and energy consumption, according to the table compare with other variable with a total resistance of 21.4692, this material has the highest resistance in the building and the lowest heat transfer coefficient (U) overall, at 0.0466.

Better insulating qualities are indicated by the combination's lower total heat transfer coefficient (Ut) of 3.8163. As a result, at 110760, the heat load (Q total)

is reduced fig.6, yielding the lowest cooling load of 9.23 tons in fig.7. At 498.42 units, the equivalent energy usage is likewise the lowest.

All of these elements show that polyurethane foam is the best material for reducing the cooling load and energy consumption, which makes it the best option for insulation in buildings that aim for energy efficiency. Polyurethane Foam is the best material for building energy performance based on the provided data.

11. Phase Change Material

PCM is a thermal storage material during the solidification and melting the process. During melting it absorb large amount of heat from the environment.

A total of 15 commercially available PCMs analyses for the hot and dry climate of Multan and energy consumption analysis is 2 hours Air conditioner working in daily. PCM Used technique mentioned in fig 8 it depends on the environment temperature and thickness of layer.

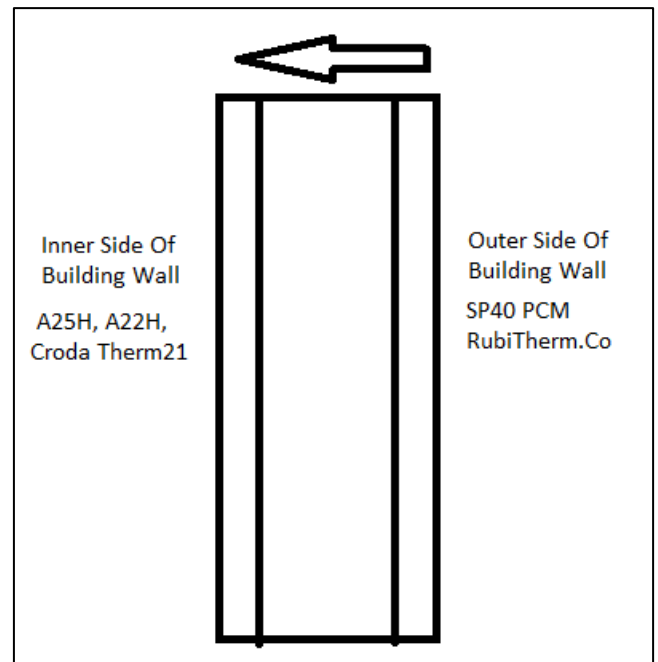


Fig:-8 PCM Using Techniques

Table: 6. Total Heat Load of Building with Building Insulation Material

Material	Thermal Conductivity (K) (BTU/(h.ft.F))	Resistance Of Building Wall (Rtotal) h.ft2.°F/Btu	Overall Heat Transfer Coefficient of Wall (U) Btu/h.ft2.°F	Overall Heat Transfer Coefficient (Ut) Btu/h.ft2.°F	Heat Load (Q total) Btu/h	Cooling Load (Tons)	Energy Consumption (KWh)
Croda Therm24	0.1675	5.2261	0.1913	4.3954	133000	11.08333333	598.5
Croda Therm24W	0.127	5.9686	0.1675	4.3002	129920	10.82666667	584.64
Croda Therm21	0.104	6.6478	0.1504	4.2317	127210	10.60083333	572.445
Croda Therm19	0.132	5.8523	0.1709	4.3135	130450	10.87083333	587.025
Pure temp23	0.144	5.6061	0.1784	4.3435	131630	10.96916667	592.335
Pure temp20	0.132	5.8523	0.1709	4.3135	130450	10.87083333	587.025
Pure temp18	0.15	5.4978	0.1819	4.3576	132190	11.01583333	594.855
RT25HC	0.115	6.2891	0.159	4.266	128570	10.71416667	578.565
RT22HC	0.115	6.2891	0.159	4.266	128570	10.71416667	578.565
RT21HC	0.115	6.2891	0.159	4.266	128570	10.71416667	578.565
A25H	0.104	6.6478	0.1504	4.2317	127210	10.60083333	572.445
A22H	0.104	6.6478	0.1504	4.2317	127210	10.60083333	572.445
SP25E2	0.288	4.2519	0.2352	4.5707	140600	11.71666667	632.7
SP24E	0.288	4.2519	0.2352	4.5707	140600	11.71666667	632.7
SP21EK	0.288	4.2519	0.2352	4.5707	140600	11.71666667	632.7
SP50	0.346	4.0958	0.1165	4.0958	121830	10.1	548.23

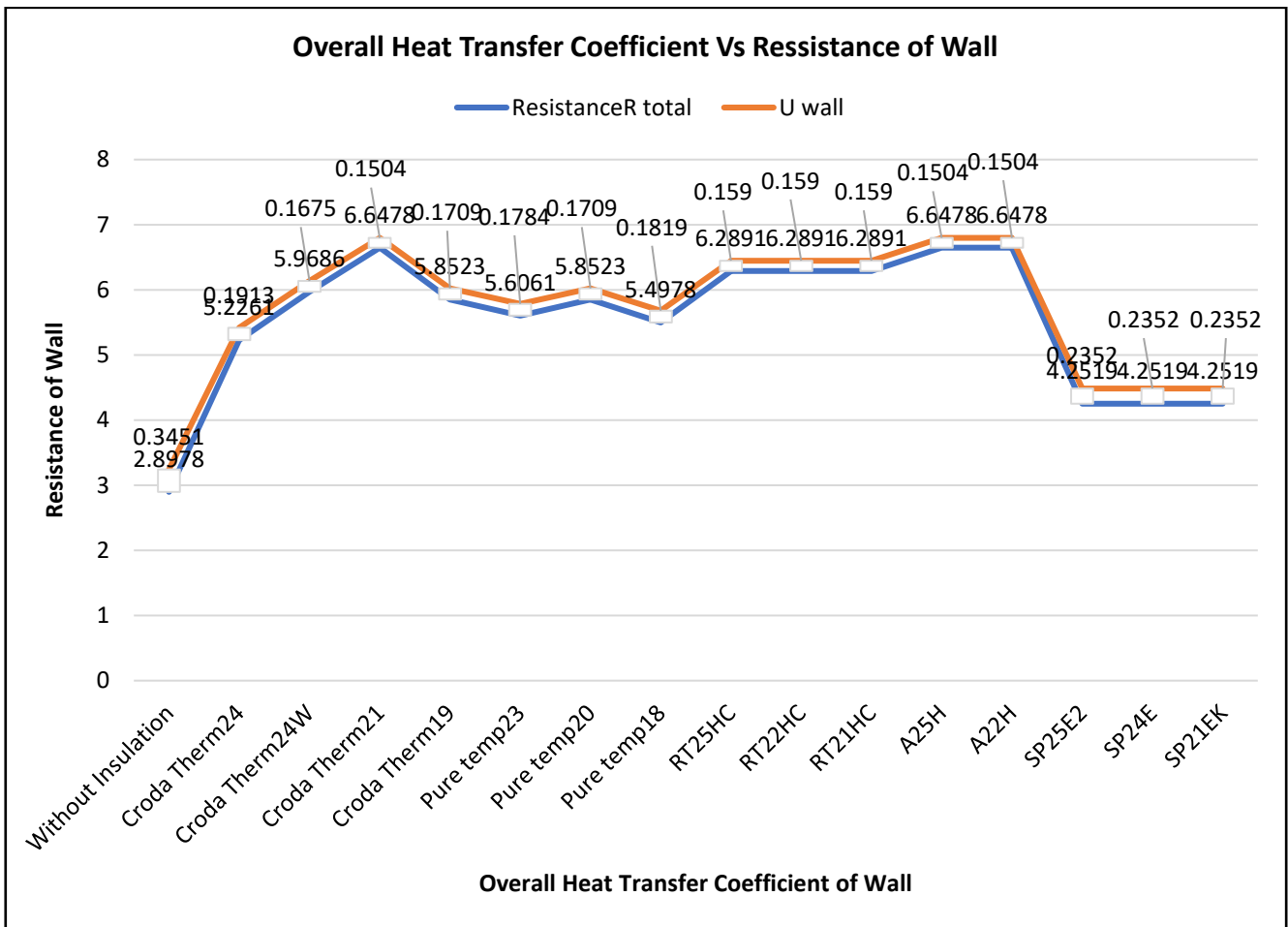


Fig:-9 Comparison of Overall Heat Transfer Vs. Resistance of Wall with Different PCM Materials

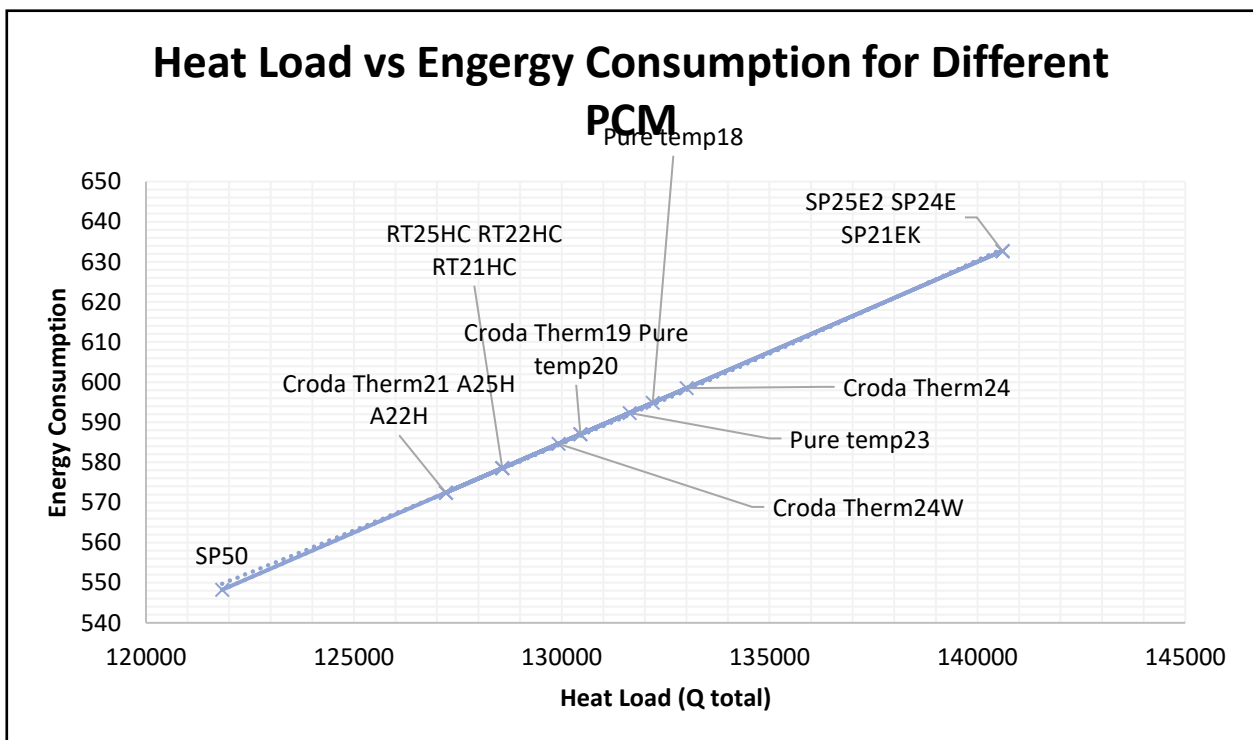


Fig: 10. Heat Load versus Energy Consumption

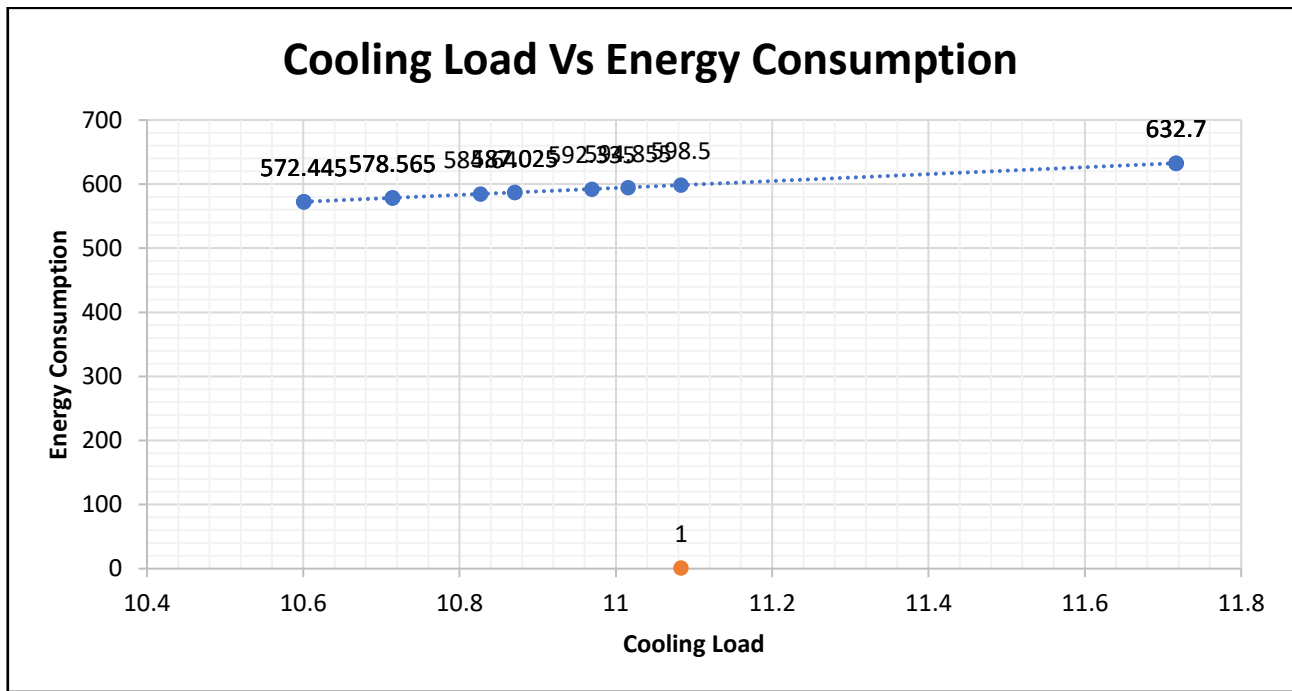


Fig: 11. Cooling versus Energy Consumption

The four materials examined in Table 6, PCM materials Croda Therm21, A25H, and A22H perform the best in terms of minimizing cooling load and energy consumption in relation to their overall heat transfer coefficient, according to the data supplied with a comparatively low thermal conductivity of 0.104, Croda Therm21 has good insulating qualities. With one of the highest building resistances (R_{total}) of any material, it results in a wall with a low overall heat transfer coefficient (U) of 0.15004. With one of the lowest overall heat transfer coefficients (U_t) of 4.2317, the material exhibits exceptional heat-resistance. Thus in Fig 9 Croda Therm21's heat load (Q_{total}) is 127210, which leads to a cooling load of 10.60083333 tonnes and an energy consumption elaborated in fig 10 & 11. The performance metrics of A25H (and A22H) are the same as those of Croda Therm21 since they have the same thermal conductivity, resistance, and overall heat transfer coefficients. These metrics include a heat load (Q_{total}) of 127210, a cooling load of 10.60083333 tonnes, and an energy consumption of 572.445 units. The best materials in this dataset are therefore Croda Therm21, A25H, and A22H, which show the lowest

cooling loads and energy usage as a result of their superior insulating qualities, as shown by their low overall heat transfer coefficients. These materials are the most efficient options for thermal insulation in buildings since they are very good at lowering cooling requirements and energy consumption. To optimize the energy performance of PCM materials in Table 6 Croda Therm21, A25H, and A22H all have identical values for thermal conductivity, U_{total} , Q_{total} and cooling load. These materials perform. SP50 Phase change material is new and innovate material stable performance throughout the phase change class.

12. Conclusion

In this study examined the use of PCM in building envelopes of the residential building for the climate condition of Multan Pakistan is one of the effective methods for energy conservation in buildings. The Climatic consultant analyzes the ASHRE Design Model 2005 for attaining the Comfortable hours without any addition of any artificial Support. Building design must regulate natural conditions to make indoor spaces 14.1 % comfortable without the need for artificial support

and the human comfort zone. Low water content in the air, extreme heat, and intense sun radiation must all be considered in design. PCM Polyurethane foam, A25H, A22H, Croda Therm21 having a layer thickness of 10 mm is then placed at the inner side layer of external walls single story residential house but the SP50 PCM with the thickness of 50mm Used outer surface before the phase brick or Plaster. A monthly average energy reduction of 19.5% can be achieved in total heating and cooling consumption. The PCM installation is found to be cost effective in Multan. This study has revealed the great potential of PCM and its suitability for enhancing the energy efficiency of buildings in different climates of Pakistan. In Future encapsulation technique is very helpful for enhancing the energy efficient buildings.

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