JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Comprehensive Analysis of Phase Change Materials for Cold Storage

Laxmi Raikwar Singadiya[a,*], J.K Shrivastava[a], Rajesh Kumar Singadiya[a,]

[a]*Chemical Engineering Department Ujjain Engineering college Ujjain 456006 India*

ABSTRACT: Phase change materials (PCMs) are mainly used for energy in cold storage applications and enhancement potential of releasing and storing heat during phase transformation from solid to liquid respectively. In building construction materials or cold storages, incorporation of PCMs is a booming technology. Lot of problems exists in appropriate selection of PCMs in recent trends due to its high cost and poor thermal conductivity as well as increase in virus infectivity. Paper focuses on comprehensive analysis of various PCMs (i.e. paraffin, polyethylene glycol 400, HS01, OM03, organic mixture and Salt hydrates) used in cold storages for vegetables in India to make them energy efficient.

Keywords: Cold Storage (CS), Phase Change Material (PCM), Latent Heat Thermal Energy Storage Systems (LHTES), **HS01, Salt Hydrates and Water.**

Highlights:

1. To overview of Phase change material for thermal energy storage
2. To overview and summary of fruits as well as vegetables state wise contribution in cold storage. Author's analysis in cold storages for temperature variations to store fruits, vegetables and ice-cream.
3. To analysis of different phase change material according to their chemical reaction, temperature and latent heat with its applications, types and properties.
4. To find phase change material like HS01, OM03 and water with its technical details to develop new cold storage in upcoming days.
5. To conclude overall summary of research studies, analysis and survey, so new cold storage may be developed for vegetables in Madhya Pradesh.

I. INTRODUCTION

The research furnishes an evaporative strengthen cold storage system over against a hot air stream is cooled and the cooled air stream is subsequently passed into contact with a cold storage unit. Cold chain arrangement is a kind of system, which usually refers to refrigerated and frozen goods such as vegetables, fruits, food, biological or medicine products, in the production, transportation, consumption and sale of each link before, always maintained at the optimal refrigeration temperature, at the same time to maintain quality and reduce loss [1, 2]. The application of phase change material (PCM) maintained inside cold space temperature 1 to 4 ^{0}C lower than without PCM in a cold storage facility [2]. In PCMs heat may be stored by using a phase change in the material. PCMs have a larger capacity for storage as compared to water [3].

Food safeties have become more concerns with an increasing population and demand in coming years [4]. PCM has been tested under extremely low , extremely high and alternating temperature transportation situation [4]. The stability of Phase change material for cold storage could improve and of efficiency the building thermal environment [5]. PCMs have received great observation in various applications, mainly, storage thermal energy in latent heat thermal energy storage systems (LHTES) [6,7]. It incorporated phase change material for cold chain insulated container which has temperature controlled transportation for the range of 2 to 8 degree C.

A methodology to measure and predict the thermal behavior of the phase change materials at the sub-zero temperature [8]. A novel solar Phase change material wall technology is used for building in hot summer and cold winter regions [9]. They had used water as a PCM and polyurethane for wall insulation.

The fundamental benefits of thermal energy storage (TES) system are summarized below [13]:

1. Efficiency: use of energy and achieve a better.
2. Environmental effects: minimize pollution, less greenhouse gases (GHGs) emissions.
3. Sustainability: improved performance of system and reliability via incorporation of more renewable energies.
4. Economics: operational and capital costs reduced to save money

II. COLD STORAGE

In June 2020, the Government of India amended the Essential Commodities Act (1955) in an attempt to increase the size and range of buyers available to farmers and also the cold storage sector encourage investments [2]. In December, 2014 National Horticulture Board conducted a survey to estimates the total capacity of cold storage in India at 31.8 million MT [11]. Cold storage is the most remarkable process of the spread of food borne diseases and preventing post harvest food losses globally [12]. Now a day the demand of the fresh fruits and vegetables has increased significantly [16]. In recent work suggests that isometric cold storage has the capacity to eliminate potentially harmful bacteria [17]. Figure 1 shows state wise cold storage capacity per horticulture in lakh tone. In this figure Gujarat play vital role in production but eleven lowest position of Madhya Pradesh for cold storage. In figure 2 describes contribution of cold storages in India.

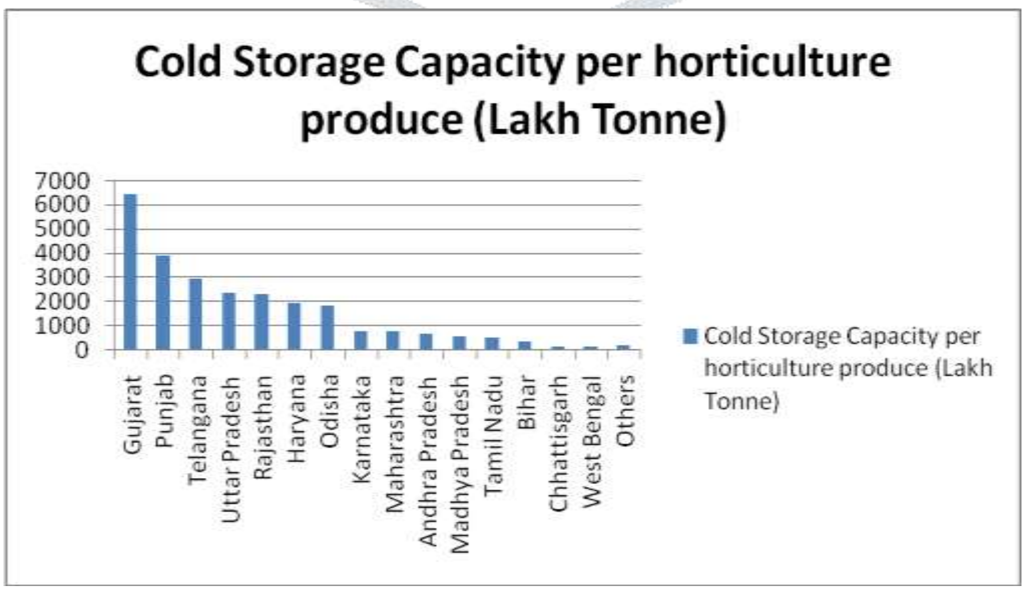

Figure 1: Cold Storage Capacity[14]

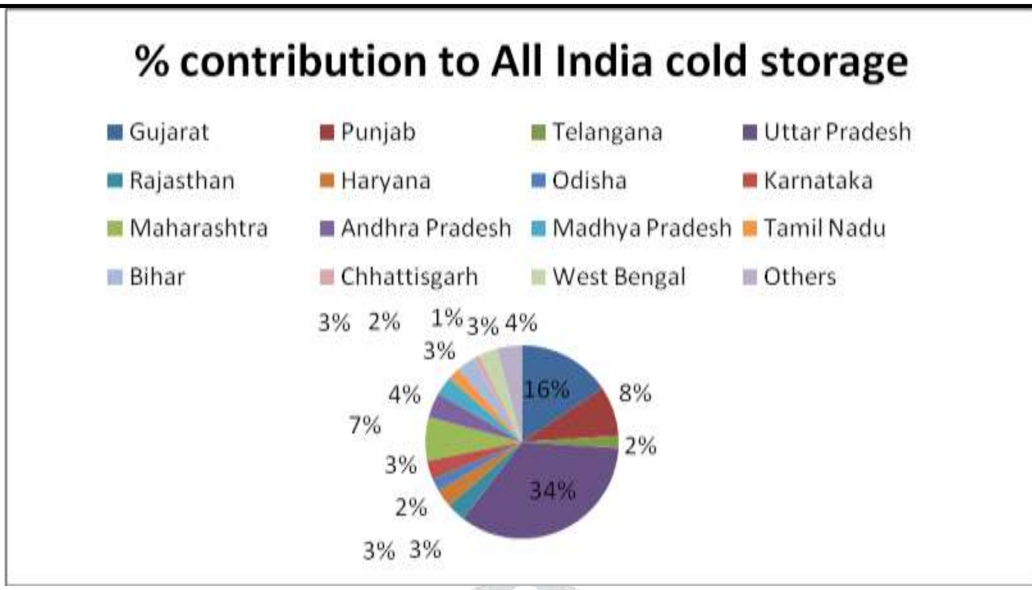

Figure 2: State wise contribution of cold storages capacity[14]

Cold storages of fruits with its temperature range and sensitivity are presented below in table 1. Thermal incompatibility of fruits and its temperature range and temperature range for cold storages are presented in table 1.

Table: 1 Thermal incompatibility of fruits and its temperature range

Sr. No.	Products	Sensitivity	Temperature Range
1	Apple, grape, carrot and onion	not sensitive	0-4°C
2	Mango, orange, potato and tomato	moderately sensitive	4-8°C
3	Pineapple, banana, pumpkin and lady finger	sensitive to cold	>8°C

There is some analysis of cold storage of ice cream, frozen, vegetables and food by researchers. Temperature range will be analyzed therefore selection of phase change materials for cold storage of vegetables will be determined.

Table: 2 Temperature ranges for cold storages

Sr. No.	Author’s	Cold Storage	Temperature Range
1.	Donhowe & Hartel[35]	Storage of ice cream	-15 and -5 °C
2.	Phimolsiripol et al[36]	Storage of frozen	-18 and ± 5 °C
3.	Gormley et al[37]	Storage of frozen	-60 and -30 °C
4.	Håkon Selvnes et al[3]	Storage of food	20 and -60 °C
5.	Amit K Jaiswal[38]	Storage of Fruits and Vegetables	2 and 8 °C
6.	Siti Aishah Hadawiah Ahmad et al[39]	Tropical fruits	5-13 °C

There are different categories and applications of cold storages about fruits and vegetables [31]:

- Freezing Fruit & Vegetable
- Cold Storage of Fruit & Vegetable
- Post Harvest Handling of Fruit & Vegetable
- Pre-Cooling & Storage Facilities
- Harvest and Storage of Fruit & Vegetable
- Storage of Home-Grown Vegetable

- Storage Operation of Fruit & Vegetables
- Storing Fresh Vegetable & Fruit
- Fruit and Vegetable Processing
- Tunnel Forced-Air Coolers for Fresh Fruit & Vegetable
- Containers and Packaging Fruit & Vegetable
- Aflatoxin B1 Production in Chilies

The advantages that can be attained from combining diverse nutrition-sensitive market arbitration, and stress the need for policies that narrow the fruit & vegetable cold storage shortage that exist away from more lucrative markets in developing countries [40]. In cold storage thermal energy requirements as per uses of phase change materials enlists following properties like an appropriate operating temperature range, which is depending on the application, low degree of super cooling, Higher energy density, thermal conductivity, corrosion resistance, chemical and physical stability, undamaging, toxic, flammable, or explosive, Small volume change and vapor pressure, Low cost and available in large quantities.

III. PHASE CHANGE MATERIAL

A. T. Waterman submitted the first report of invention about the phase change material in the early 1900s. Phase Change Materials are easier to manage and design than thermo chemical heat storage technology [6]. The decrease of outlet air temperature and heat flux as time passes can be suggested by the enhancement of PCM solid thickness and, then, of the conductive thermal resistance with time [9]. In 1980, PCMs has been integrated in the energy storage system on buildings[10]. PCMs are implemented to minimize heating and cooling loads between the building envelope due to its enormous potential of energy storage during solidification and melting, by that maintaining an acceptable thermal comfort [15-16]. PCM in the refrigerated truck is a reliable process of cold storage because it can have very low melting points and have high latent heat of melting [23]. PCMs can be classified [32, 34] as liquid gas, liquid solid, gas solid and solid-solid also further classified as organic compounds, inorganic compounds and eutectic mixtures. In Eutectics mixtures include organic-organic, inorganic-organic and inorganic- inorganic [41-42]. In heating and cooling PCMs are extensively applied[43-44]. Ice, water and latent heat storage systems are common methods to achieve a cold storage[45-47]. The temperature will change phases of material like the temperature minimize, the material changes phase from liquid to solid and the temperature maximize, the material changes phase from solid to liquid. The PCM preserv its latent heat without any change in physical or chemical belongings over thousands of cycles. A higher value of heat stored offer by PCMsa per unit volume (up to 50 kWh/m3), ranging from five to fourteen times additionally to conventional sensible-heat storage materials. Organic PCMs include paraffin's and non-paraffin like fatty acids, esters, glycols and alcohols. Inorganic PCMs hydrated metallic and salts.

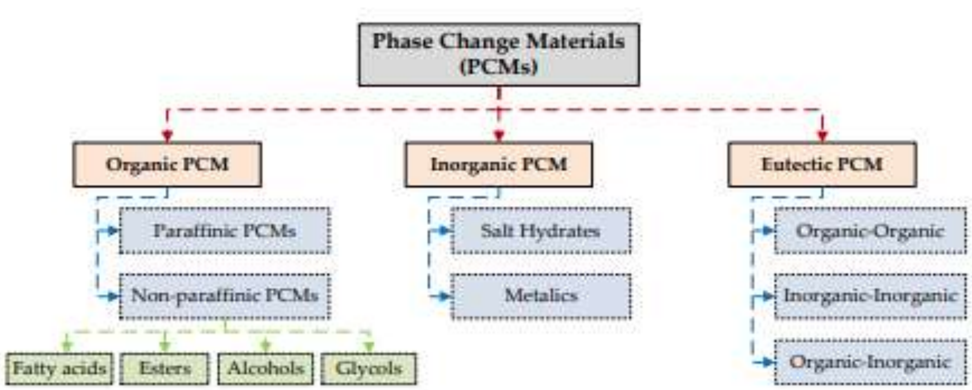

Figure: 3 Types of Phase Change Material [18, 19]

Phase change materials are commonly used in some temperature sensitive such as solar energy applications, peak conformity transfer, bio refrigeration system and domestic hot water tank. The applications of polyethylene glycol 400 (PEG400) PCMs are used for development of cold storage facility to improve its thermal performance. A methodology to measure and predicts the thermal behavior of the phase change materials at the sub-zero temp. Water, propylene glycol ($C_3H_8O_2$), Glycerin ($C_3H_8O_3$), Paraffin oil, sodium and polyacrylate, ($C_3H_3NaO_2$) as a phase change material for cold energy storage system. In inorganic phase change materials (Tm) latent heat [32] and thermal conductivity [33] are two most important selection criteria for PCM. Various PCMs are given in table 3.

Table: 3 Phase change material for cold storage

Sr. No.	Phase Change Material	Chemical Reaction	Temperature Tm/°C	Latent Heat
1	Salt Hydrate[53]	Mn(NO3)2·6H O	25.8	126 kJ/kg
2.	Salt Hydrate[54]	$LiClO_3.3\ H_2O$	8	253 kJ/kg
3.	Water	H_2O	0	333 kJ/kg
4.	Paraffin[55]	C_nH_{2n+2}	30	150-250 kJ/kg
5.	Paraffin C_{16}-C_{28}[56]	CH_3-(CH_2)n-CH_3	44	189 kJ/kg
6.	Sodium thiosulfate penta hydrate [104]	$Na_2S_2O_3 \cdot 5H_2O$	48	210 kJ/kg
7.	M550[105]	_______	552	251 kJ/kg
8.	H500[105]	_______	509	260 kJ/kg
9.	HS01[62]	_______	0	350 kJ/kg
10.	OM03[61]	_______	3.5	229 kJ/kg

Paraffin- C_nH_{2n+2} as per availability is one of the wide analyzed phase change material in thermal energy storage [34] application, non-corrosive nature and relatively low-cost. Paraffin is generally consist of straight long chain alkenes, the melting point and the chain length depends upon heat release of paraffin. so advantages with effective from moderate flammability and low thermal conductivity flourished only applicable to small scale and only for low temperature application. Paraffins[55] with temperature between 30°C and 60°C have particular utilization in improving the efficiency for thermal buffering of batteries and electronics latent heat of fusion of paraffin is 150-250 kJ/kg and liquid density is 700 - 850 kg/m3[8]. Researchers and academicians determine paraffin has a melting temperature from -12 to 71°C with a latent heat of 128–198 kJ/kg.

The paraffin as PCM but tends to have indigent thermal conductivity. This may be improved by produces a high surface area like microencapsulation. To maximize performance of PCM, the thermal heat transfer require to compare with the flow of heat to it. In the case of heat transfer systems, where in fluids are used in slurris of PCM, the thermal conductivity of fluid domination the system performance in releasing it for heat output and absorbing at the point of heat input in thermal kinetic energy .

Polyethylene glycol 400 (PEG400)- is the wide studied phase change material for cold storage facility, the temperature ranges of 3 °C to 6 °C[2]. Melting latent heats of neat PEG400 in the range from 105.3 to 117.3 $J \cdot g^{-1}$ are normally reported for Polyethylene glycol 400. PEGs with several average molecular weights were first melt at 50–70°C.

The merits of salt hydrates are high alloy latent temperature, proportionate high thermal conductivity, and small volume changes in melting. HS01 is salt hydrate type phase change material. Melting point of Water as well as HS01 PCM-HS01P is 0 °C (32 °F). HS01 is salt hydrate type PCM its latent heat is 290 J/g. Specific heat, liquid 3.60 J/(g·°C). The HS01/I are chemical based an inorganic PCM having nominal freezing temperature of 10 °C. Thermal energy of HS01 as latent heat in their crystalline form. While changing phase this latent heat is absorbed or released, empowering in maintaining the ambient temperature. Ternary salt-water solution is used as phase change material to facilitate the frozen food cold storage and transportation.

PCM microcapsules enlarge the application of the PCMs, due to properties of PCM chemical and thermal stabilization, suitable solid-to-liquid phase transition, and higher amount of energetic changes.

Salt hydrates provides thermo chemical storage of heat in compact and efficient way to store solar energy. The merits of the salt hydrates find the storage capacity, cost and operating conditions of the thermo chemical storage system. The reversible reaction of hydration and/or dehydration of a salt hydrate is shown in Eq. 1.

$$salt + xH_2O \leftrightarrow salt.xH_2O + heat \quad \ldots\ldots (1)$$

IV. APPLICATIONS AND PROPERTIES OF PCM

PCMs are used for following applications

- To improve thermal stability in the time of power loss in cold storage [13]
- In building efficiency field[48]
- In Solar Water Heating Systems[49]
- In Heat Management in Photovoltaics[50]
- To store heat in Hybrid and Electric Vehicles [51]
- The solar power plants and solar cooling [78]
- To waste heat recovery systems[79]
- To solar dryers in agricultural industry[80]
- To preservation of food and pharmaceutical products [81]

Various PCMs used in cold storages, presented in table 4.

Table: 4 Phase change materials for cold storage

Sr. No.	Property of Material	Paraffin Wax	Hydrate Salt	Non-Paraffin Organics	Metallic's	Water
1.	Heat of Fusion[92,93]	High	High	High	Medium	333.5 Joule/gram
2.	Thermal Conductivity[95]	Very Low	High	Low	Very High	0.598 W/m·K
3.	Melting Temperature[96]	-20 to 100+ °C	0 to 100+ °C	5 to 120+°C	150 to 800+°C	0 °C
4.	Latent Heat (kJ/kg)[97]	200 to 280	60 to 300	90 to 250	25 to 100	2,260 kJ/kg
5.	Corrosive[98]	Non-Corrosive	Corrosive	Mildly Corrosive	Varies	Corrosive
6.	Economics	Rs. 100 Approx.	Rs. 10 Approx.	Rs. 1000 Approx.	Rs. 10 to 100 Approx.	Rs. 1 to Rs. 10 Approx.
7.	Thermal Cycling[99]	stable	Unstable over repeated	Elevated Temperature Can Cause Decomposition	Stable	Stable
8.	Weight	Medium	Light	Medium	Heavy	Medium

V. IMPORTANT FINDINGS

There are some important findings pointed out after critical analysis of various researches, author's view, and data sheet of different phase change materials for cold storages. Research papers of different journals, reports, chapters as well as proceedings about phase change materials for cold storages are studied to determining selection of phase change material for implementation in storages of vegetables and fruits at Indore, India. Data sheet of phase change material of HS01 and OM03 presented in table 5.

Table: 5 Technical details of Phase change material of HS01 and OM03

Property	**Value HS01**	**Value OM03**
Melting Temp (0 °C)	1	4
Freezing Temp (0 °C)	1	3
Latent Heat (kJ/kg)	350	229
Liquid Density (kg/m3)	1010	835
Solid Density (kg/m3)	924	912
Liquid Specific Heat (kJ/kgK)	3.9	1.91
Liquid Thermal Conductivity (W/mK)	0.55	0.146
Solid Thermal Conductivity (W/mK)	2.2	0.224
Base Material	Inorganic	Organic
Thermal Stability (Cycles)	~3000	~2000
Maximum Operating Temperature (0C)	~80	120
Test Method HS01	**Test Conditions HS01**	
ASTM D891-95	30°C	
ASTM D792-08	-20°C	
Test Method OM03	**Test Conditions OM03**	
ASTM D891-95	30°C	
ASTM D792-08	0°C	

VI. CONCLUSION

Phase change material thermal properties decline significantly with temperature for vegetables cold storages. As per research studies paraffin, polythene glycol, salt hydrates (HS01), OM03 and water may be used as phase change material to develop cold storage for vegetables. The PCM is chemically and thermally stable for cold storage and easily available. The most expensive part of storing vegetables or fruits in cold conditions would be customization. Heat is absorbed or released when the materials change states in OM03 and HS01. There will be two phase change material which can be used for cold storage in near future. Experimental analysis of phase change materials HS01 and OM03 based cold storage for vegetables may be provided.

REFERENCES:

1. Lin Zheng, Wei Zhang and Fei Liang "A Review about Phase Change Material Cold Storage System Applied to Solar Powered Air-Conditioning System" Advances in Mechanical Engineering, Volume 9(6), page 1–20, year 2017.
2. https://www.prsindia.org/sites/default/files/bill_files/ECA.pdf.
3. HåkonSelvnes, Yosr Allouche, Raluca Iolanda, Manescu Armin, Hafner "Review on Cold Thermal Energy Storage Applied to Refrigeration Systems Using Phase Change Materials" Thermal Science and Engineering Progress, Elsevier, year 2021.

4. Li Huang, and Udo Piontek "Improving Performance of Cold-Chain Insulated Container with Phase Change Material: An Experimental Investigation" Applied Science, Volume 7(12), Year 2017.
5. Qudama Al-Yasiri, Márta Szabó "Paraffin as a Phase Change Material to Improve Building Performance: An Overview of Applications and Thermal Conductivity Enhancement Techniques" Renewable Energy Environmental Sustainability, Volume 6, year 2021.
6. Jingjing Zhang, Hairong Li, Junyang Tu, Ruonan Shi, Zhiping Luo, Chuanxi Xiong, and Ming Jiang "Shape Stability of Polyethylene Glycol/Acetylene Black Phase Change Composites for Latent Heat Storage" Advances in Materials Science and Engineering, Hindawi, year 2018
7. P.pingali, "Westernization of Asian Diets and The Transformation of Food Systems: Implications for Research and Policy" food policy, Elsevier, ScienceDirect, Volume 32(3), year 2007.
8. Bi Y, Guo T, Zhang L, Zhang H, Chen L. Experimental study on cool release process of gas-hydrate with additives. Energy and Buildings, Elsevier, ScienceDirect, Volume 41(1), year 2009
9. Ali Mousazade, Roohollah Rafee, Mohammad Sadegh Valipour "Thermal Performance of Cold Panels with Phase Change Materials in a Refrigerated Truck" International Journal of Refrigeration, Elsevier, ScienceDirect, Volume 120, year 2020
10. De Falco Marcello "Phase Change Material as Energy Material for Cold Storage and its integration in Civil Air Conditioning Systems: Material Properties and on Field Application" Advances in Engineering Research (AER), volume 102 Second International Conference on Mechanics, Materials and Structural Engineering (ICMMSE), year 2017
11. https://www.mofpi.gov.in/sites/default/files/OpportunitiesinColdChainSectorinIndia.pdf
12. Bi Y, Guo T, Zhang L, Zhang H, Chen L. "Experimental Study on Cool Release Process of Gas-Hydrate With Additives" Energy and Buildings, Elsevier, Volume 41, year 2009
13. Samer Kahwajia, Michel,Johnsonb, Ali, Kheirabadic, Dominic, Groulxbc Mary,Anne White "A Comprehensive Study of Properties of Paraffin Phase Change Materials for Solar Thermal Energy Storage and Thermal Management Applications" Energy, Volume, Pages 1169-1182, year 2018
14. B. He, V. Martin, F. Setterwall, "Phase Transition Temperature Ranges and Storage Density of Paraffin Wax Phase Change Materials", Energy, Volume 29(11) year 2004
15. Du, J., Nie, B., Zhang, Y., Du, Z., & Ding, Y. Cooling performance of a thermal energy storage-based portable box for cold chain applications. Journal of Energy Storage, 28, 101238 Year 2020
16. Laila Khatraa, Hamid El Qarniaa, Mohammed El Ganaouib "Numerical Study of a Cold Storage System for Air Cooling" International Conference On Materials And Energy, ICOME, Year 2015.
17. Mohammed M Farid, Ali Nasser Khalaf "Performance of Direct Contact Latent Heat Storage Units With Two Hydrated Salts" Pergamon Solar Energy volume 52(2),Year 1994
18. Osterman E, Butala V and Stritih U. "PCM Thermal Storage System for Free Heating and Cooling of Buildings" Energy Buildings, page 125–133 year 2015
19. Hasnain SM. "Review on Sustainable Thermal Energy Storage Technologies, Part 1: Heat Storage Materials and Techniques" Energy Converters Manage, page 1127–1138 year 1998
20. Vivek Raj, Goswami TK "Use of Phase Change Material (PCM) for The Improvement of Thermal Performance of Cold Storage" Moj Current Research and Reviews, Volume 2(1), page 49–61,Year 2018
21. National Centre for Cold Chain Development, "Challenges to Cold Chain Development" Ministry of Agriculture year 2019.
22. Qudama Al-Yasiri, Marta Szabo "Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis" Journal of Building Engineering, ScienceDirect, Volume 36, Year 2021.
23. H. Ye, Y. Wang, F. Qian "Experimental Study on Thermal Comfort Improvement of Building Envelope With PCM Energy Storage" eBook ISBN 9781003000716 CRC Press, Page 213, Year 2019.
24. B.Y. Yun, J.H. Park, S. Yang, S. Wi, S. Kim, Integrated Analysis of The Energy and Economic Efficiency of PCM as an Indoor Decoration Element: Application to An Apartment Building, Solar Energy, ScienceDirect, page 437–447, Volume 196 Year 2020.
25. Tomasz Tietze , Piotr Szulc, Daniel Smykowski , Andrzej Sitka and Romuald Redzicki "Application of Phase Change Material and Artificial Neural Networks for Smoothing of Heat Flux Fluctuations", MDPI Energies, Volume 14(12), year 2021.
26. K. Faraj, M. Khaled, J. Faraj, F. Hachem, C. Castelain, "Phase Change Material Thermal Energy Storage Systems for Cooling Applications in Buildings: A Review", Renewable. Sustainable Energy Reviews, ScienceDirect, Volume 119, year 2020.
27. Qureshi WA, Nair N-KC, Farid MM. Impact of energy storage in buildings on electricity demand side management. Energy Convers Manage p.52:2110–20 year 2011.
28. Sidney S, Dhasan M, C. S, Harish S. "Experimental investigation of freezing and melting characteristics of graphene-based phase change nano composite for cold thermal energy storage applications" MDPI, Applied Science, Volume 9(6), year 2019.

29. De Gracia A, Oró E, Farid MM, Cabeza LF "Thermal Analysis of Including Phase Change Material in A Domestic Hot Water Cylinder" Applied Thermal Engineering, ScienceDirect, Volume 31(17-18), year 2011.
30. Gabriel Zsembinszki, Angel G. Fernandez, Luisa F. Cabeza "Selection of the Appropriate Phase Change Material for Two Innovative Compact Energy Storage Systems in Residential Buildings" MDPI Applied Science, year 2020.
31. Jeff Ihnen "Phase Change Materials for Grid-Interactive Efficient Buildings (GEBs)", MichaelsEnergy, year 2020.
32. M.M. Mac Devette, T.G. Myers "Nanofluids: An Innovative Phase Change Material for Cold Storage Systems?", International Journal of Heat and Mass Transfer, year 2015
33. E. Borri,J Y Sze,A Tafone,A, Romagoli, and Y Li, Y "Experimental And Numerical Characterization of Sub-Zero Phase Change Material for Cold Thermal Energy Storage" Journal of Applied Energy, Year 2020.
34. C.Luo, L.XV, J,Ji, M. Lia and D. Sun Y "Experimental Study of A Modified Solar Phase Change Material Storage Wall System", Journal of Energy ,Year 2017.
35. Matthew J. Powell-palm, Boris rubinsky "A Shift from the Isobaric to Isochoric Thermodynamic State Can Reduce Energy Consumption and Augment Temperature Stability in Frozen Food Storage" Journal of food engineering, Year 2019.
36. Powell palm M.J., Preciado, J. Lyu C.,Rubinsky B., "Escherichia Coli Viability in An Isochoric System At Subfreezing Temperatures" cryobiology,Year 2018.
37. G. Li, "Energy and Exergy Performance Assessments For Latent Heat Thermal Energy Storage Systems" Renewable Sustainable Energy Revolution, Year 2015.
38. De-Kun Liu, Cong-Cong Xu, Chun-Xiao Guo, Xin-Xin Zhang "Sub-Zero Temperature Preservation of Fruits and Vegetables: A Review" Journal of Food Engineering, Year 2019.
39. Alptug yataganbaba, Bengi Ozkahraman, Irfan kurtbas "Worldwide Trends on Encapsulation of Phase Change Materials: A Bibliometric Analysis (1990-2015)" Applied energy, Elsevier, Year 2016.
40. Mills A., Farid M., Selman JR, Al-Hallaj S., "Thermal Conductivity Enhancement of Phase Change Materials Using A Graphite Matrix" Applied Thermal Engineering, Year 2006.
41. Yi Zhao, Xuelai zhang, Xiaofeng xu, Shihua zhang "Development of Composite Phase Change Cold Storage Material And Its Application in Vaccine Cold Storage Equipment" Journal of Energy Storage, Elsevier, year 2020.
42. Daniel P.Donhowe, Richard W.Hartel "Recrystallization of Ice during Bulk Storage of Ice Cream" Journal, Pages 1209-1221, Year 1996.
43. Phimolsiripol Y,Siripatrawan U, Tulyathan V, Cleland DJ "Effects of Freezing and Temperature Fluctuations During Frozen Storage on Frozen Dough and Bread Quality" Journal of Food engineering, Volume 84(1), page 48-56, Year 2007.
44. Ronan Gormley,Thomas Walshe,Karen Hussey,Francis Butler "The Effect of Fluctuating vs. Constant Frozen Storage Temperature Regimes on Some Quality Parameters of Selected Food Products" LWT - Food Science and Technology Volume 35(2), Pages 190-200, year 2002.
45. Amit K Jaiswal "Nutritional Composition and Antioxidant Properties of Fruits and Vegetables" book chapter, ISBN 978-0-12-812780, ScienceDirect, Pages 745-756, year 2020.
46. Siti Aishah Hadawiah Ahmad, Mohd Nizam Ab Rahman and Ariff Azly Muhamed "Optimal Temperature in Cold Storage for Perishable Foods" Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, year 2020.
47. G.S. Cooper,B. Shankar,K.M. Rich,N.N. Ratna,M.J. Alam,N. Singh,S. Kadiyala "Can Fruit And Vegetable Aggregation Systems Better Balance Improved Producer Livelihoods With More Equitable Distribution?" World Development, SciencesDirect, Year 2021
48. X. xu,X. Zhang, S. Liu, "Experimental Study on Cold Storage Box With Neon Composite Phase Change Material and Vacuum Insulation Panel" International journal of Energy Res., ScienceDirect, Page 4429-4438, year 2018.
49. N. Beaupere, U. Soupremanien,L. Zaleski "Nucleation Triggering Methods in Super Cooled Phase Change Materias(PCM), A Review" Thermochim. Acta, Year 2018.
50. Yutang fang, Huimin yu, Weijun wan, Xuenong gao, zhengguo zhang "Preparation and Thermal Performance of Polystyrene/N0tetradecane Composite Nano Encapsulated Cold Energy Storage Phase Change Materials" Energy conservation and management, ScienceDirect, page 430-436, Year 2013.
51. Mehling H., Cabeza LF,Hippeli S., Hiebler S. "PCM-Module to Improve Hot Water Heat Stores With Satisfaction" Renewable Energy, ScienceDirect, page 699-711, Year 2003.
52. Zheng, Lin; Zhang, Wei; Liang, Fei "A Review About Phase Change Material Cold Storage System Applied To Solar-Powered Air-Conditioning System" Advances in Mechanical Engineering, Volume 9(6), year 2017.
53. Kapsalis V and Karamanis D. "Solar Thermal Energy Storage And Heat Pumps With Phase Change Materials" Applied Thermal Engineering, page 1212–1224, year 2016
54. Ghoneim A. "Comparison of Theoretical Models of Phase Change and Sensible Heat Storage for Air and Water-Based Solar Heating Systems" Solar Energy, page 209–220, year 1989.

55. Osterman E, Butala V and Stritih U. "PCM Thermal Storage System for 'Free' Heating and Cooling of Buildings", Energy Buildings, page 125–133, year 2015.
56. Kumar B. "Design, Development and Performance Evaluation of A Latent Heat Storage Unit for Evening and Morning Hot Water Using A Box Type Solar Collector" Project Report, M. Tech. (Energy Management), Indore, India: School of Energy and Environmental Studies, Devi Ahilya University, year 2001.
57. Tiwari GN, Tiwari S, Dwivedi V.K., Sharma S, Tiwari V. "Effect of Water Flow on PV Module: A Case Study" International IEEE Conference Energy Economics and Environment (ICEEE), year 2015.
58. Kraft, W. Altstedde, M.K. "Use of Metallic Phase Change Materials (Mpcm) for Heat Storage in Electric- and Hybrid Vehicles", Institution of Engineering and Technology 6th Hybrid and Electric Vehicles Conference (HEVC 2016) - London, UK 6th Hybrid and Electric Vehicles Conference, HEVC, year 2016.
59. Sharma SD, Sagara K. "Latent Heat Storage Materials and Systems: A Review" International Journal of Green Energy, year 2005.
60. Khan Z, Khan Z, Ghafoor A. "A Review of Performance Enhancement Of PCM Based Latent Heat Storage System Within The Context of Materials, Thermal Stability And Compatibility" Energy Conversion and Management, year 2016
61. Haynes WM. "Handbook of Chemistry and Physics" 91st edition, CRC Press, year 2010-2011
62. Xie N, Huang Z, et al. Inorganic salt hydrate for thermal energy storage. Applied Sciences.7:1317 year 2017.
63. Samir Soliman, Fathi "Paraffin - an Overview: Paraffin as Phase Change Material", Chapter 5, year 2020.
64. Lizhong Yang Uver Villalobos Bakytzhan Akhmetov Antoni Gil Jun Onn Khor Anabel PalaciosYongliang LiYulong DingLuisa F. CabezaWooi Leong Tan Alessandro Romagnoli "A Comprehensive Review on Sub-Zero Temperature Cold Thermal Energy Storage Materials, Technologies, and Applications: State of The Art and Recent Developments", Elsevier, year 2021.
65. National Institute of Standards and Technology. NIST Chemistry WebBook, NIST Standard Reference Database Number 69. Gaithersburg: 2020.
66. Engineering ToolBox 2001. https://www.engineeringtoolbox.com accessed February 8, 2021.
67. Håkon Selvnes,Yos rAllouche, Raluca Iolanda, Manescu,Armin Hafner "Review on Cold Thermal Energy Storage Applied to Refrigeration Systems Using Phase Change Materials" Thermal Science and Engineering Progress, Elsevier, Volume, 1 May 2021.
68. PLUSS Technical data sheet OM03, Available online: http://pluss.co.in/ accessed on 15 December, 2021.
69. PLUSS Technical data sheet HS01, Available online: https://www.pluss.co.in/upload/technical-datasheets/2019/Doc%20431_TDS%20HS%2001.pdf accessed on 15 December, 2021.
70. Gabriel Zsembinszki, Angel G. Fernández and Luisa F. Cabeza "Selection of the Appropriate Phase Change Material for Two Innovative Compact Energy Storage Systems in Residential Buildings" Applied Science, volume 10(6), year 2020.
71. Abhat, A. "Low Temperature Latent Heat Thermal Energy Storage: Heat Storage Materials," Solar Energy, Volume 30(4), page 313-332, 1983.
72. Verner, C. Phase Change Thermal Energy Storage. Thesis, Brighton University, May, 1997.
73. Pagkalos, Christos; Dogkas, George; Koukou, Maria K.; Konstantaras, John; Lymperis, Kostas; Vrachopoulos, Michail Gr., "Evaluation of Water And Paraffin PCM as Storage Media for Use in Thermal Energy Storage Applications: A Numerical Approach" International Journal of Thermo fluids, year 2019
74. H. Huang, Y. Xiao, J. Lin, T. Zhou and Y. Liu, "Improvement of the Efficiency of Solar Thermal Energy Storage Systems by Cascading a PCM Unit with a Water Tank," Journal of Cleaner Production, page 1-14, Year 2019.
75. A. Sharma, V. Tyagi, C.R. Chen, D. Buddhi, "Review on Thermal Energy Storage With Phase Change Materials and Applications" Renewable & Sustainable Energy Review, Volume 13 (2), Year 2009.
76. Shukla A., "Heat Transfer Studies on Phase Change Materials and Their Utilization in Solar Water Heaters" Thesis Report, Ph.D. Energy & Environment, Indore, India: School of Energy and Environmental Studies, Devi Ahilya University; 2006.
77. Lamberg P, Lehtiniemi R, Henell AM. "Numerical and Experimental Investigation of Melting and Freezing Processes in Phase Change Material Storage" International Journal of Thermal Science, year 2004.
78. D. Aydin, SP Casey, S. Riffat "The Latest Advancements on Thermo chemical Heat Storage Systems" Renewable and Sustainable Energy Reviews, Year 2015.
79. G. Fang, F. Tang, L. Cao "Preparation, Thermal Properties and Applications of Shape-Stabilized Thermal Energy Storage Materials" Renewable and Sustainable Energy Reviews, Year 2014.
80. SM Shalaby, MA Bek, AA. EI-Sebaii "Solar Dryers with PCM as Energy Storage Medium: A Review" Renewable and Sustainable Energy Reviews, Year 2014.
81. JM Belman-Flores, JM Barroso-Maldonado, AP Rodriguez-Munoz, G. Camacho-Vazquez "Enhancements in Domestic Refrigeration, Approaching a Sustainable Refrigerator: A Review" Renewable and Sustainable Energy Reviews, Year 2015.
82. Nomura T, Zhu C, "Microencapsulation of metal-based phase change material for high temperature thermal energy storage" Scientific Reports year 2015.

83. Gulfam R, Zhang P, Meng Z. "Advanced thermal systems driven by paraffin-based phase change materials—A review", Applied Energy. Year 2019.
84. Khan Z, Khan Z, Ghafoor A. "A review of performance enhancement of PCM based latent heat storage system within the context of materials, thermal stability and compatibility", Energy Conversion and Management year 2016.
85. Lu W, Tassou SA, "Characterization and experimental investigation of phase change materials for chilled food refrigerated cabinet applications", Applied Energy year 2013.
86. Sharif, M.K.A. Al-Abidi, A.A.; Mat, S. Sopian, K.; Ruslan, M.H.; Sulaiman, M.Y. Rosli, M.A.M. "Review of the application of phase change material for heating and domestic hot water systems" Renewable Sustainable Energy Rev. year 2015.
87. Frazzica, A. Palomba, V. Sergi, F. Ferraro, M. Cabeza, L.F. Zsembinszki, G. Oró, E. Karellas, S. Varvagiannis, S. Emhofer, J. "Dynamic Modelling of a Hybrid Solar Thermal/electric Energy Storage System for Application in Residential Buildings" In Proceedings of the ISES EuroSun 2018 Conference—12th International Conference on Solar Energy for Buildings and Industry, Rapperswil, Switzerland, year 2018.
88. Aftab W, Huang X, Zou R. "The Application of Carbon Materials in Latent Heat Thermal Energy Storage (LHTES). Therm. Transp. Carbon-Based Nanometer" 1st edition, Elsevier year 2017.
89. Nyoman Suamir I, Made Rasta I, Sudirman, Tsamos KM. "Development of Corn-Oil Ester and Water Mixture Phase Change Materials for Food Refrigeration Applications", Energy Procedia, vol. 161. Elsevier B.V. year 2019.
90. Sze JY, Mu C, Ayachi F, Yang L, Romagnoli A, Tay BK. "Highly Efficient Nanofiller Based on Carboxylated Graphene Oxide in Phase Change Materials for Cold Thermal Energy Storage" Energy Procedia year 2018.
91. Bejarano G, Vargas M, Ortega MG, Castano F, Normey-Rico JE. "Efficient Simulation Strategy for PCM-Based Cold-Energy Storage Systems" Applied Thermal Engineering year 2018.
92. Saeed RM, Schlegel JP, Sawafta R, Kalra V. "Plate Type Heat Exchanger for Thermal Energy Storage and Load Shifting Using Phase Change Material" Energy Conversation Management year 2019.
93. Selvnes H, Allouche Y, Sevault A, Hafner A. "CFD Modeling of Ice Formation and Melting in Horizontally Cooled and Heated Plates CFD Modeling of Ice Formation and Melting in Horizontally Cooled and Heated Plates" Eurotherm Seminar. Thermal energy storage, Lleida, Spain year 2019.
94. Dufour T, Hoang HM, Oignet J, Osswald V, Clain P, Fournaison L, "Impact of Pressure on The Dynamic Behavior of CO2 Hydrate Slurry in A Stirred Tank Reactor Applied to Cold Thermal Energy Storage" Applied Energy year 2017.
95. Mastani Joybari M, Haghighat F, Moffat J, Sra P. "Heat and Cold Storage Using Phase Change Materials in Domestic Refrigeration Systems: The State-of-The-Art Review" Energy Build year 2015.
96. A. Polzot, P. D. Agaro, G. Cortella, P. Gullo, "Supermarket Refrigeration and Air Conditioning Systems Integration Via A Water Storage", Proceedings of the 4th IIR Conference on Sustainability and the Cold Chain; Auckland, New Zealand, 2016
97. Calmac Corp., "Thermal Energy Storage in Supermarkets", supermarket_market_brochure_160811.pdf, 2015.
98. H. Selvnes, A. Hafner, H. Kauko, "Cold Thermal Storage Integration in A Large Industrial Refrigeration System", in: Proceedings of the 13th IIR Gustav Lorentzen Conference, Valencia, 2018, International Institute of Refrigeration, 2018.
99. F. Wang, G. Maidment, J. Missenden, R. Tozer, "The Novel Use of Phase Change Materials in Refrigeration Plant". Part 2: Dynamic simulation model for the combined system, Applied Thermal Engineering, year 2007.
100. Zhihua Zhou, Zhiming Zhang, Jian Zuo, Ke Huang, Liying Zhang. "Phase Change Materials for Solar Thermal Energy Storage in Residential Buildings in Cold Climate", Renewable and Sustainable Energy Reviews year 2015.
101. Ingersoll JG. "Simplified Calculation of Solar Cell Temperatures in Terrestrial Photovoltaic Arrays", J Sol Energy Eng year 1986.
102. Tiwari GN, Tiwari S, Dwivedi V.K., Sharma S, Tiwari V. "Effect of Water Flow on PV Module: A Case Study". International IEEE Conference Energy Economics and Environment year 2015.
103. G. Nelson, "Application Of Microencapsulation In Textiles" International Journal of Pharmaceutics, vol. 242, no. 1-2, pp. 55–62, year 2002.
104. Kondakkagari Dharma Reddy, Pathi Venkataramaiah, Tupakula Reddy Lokesh "Parametric Study on Phase Change Material Based Thermal Energy Storage System" Scientific Research, Energy and Power Engineering, year 2014.
105. Patricia Royo Victor J. Ferreira Zafer UreSam Gledhill Ana M. López-Sabirón Germán Ferreira "Multiple-Criteria Decision Analysis and Characterisation of Phase Change Materials for Waste Heat Recovery at High Temperature for Sustainable Energy-Intensive Industry" Science Direct Materials and Design Year 2020.
106. N. Essid, A. Loulizi, and J. Neji, "Compressive Strength and Hygric Properties of Concretes Incorporating Microencapsulated Phase Change Material," Construction and Building Materials, year 2019.
107. Y. Lin, C. Zhu, and G. Fang, "Synthesis and Properties of Microencapsulated Stearic Acid/Silica Composites with Graphene Oxide for Improving Thermal Conductivity as Novel Solar Thermal Storage Materials," Solar Energy Materials and Solar Cells, year 2019.