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A COMPREHENSIVE EVALUATION OF NANO PHASE MATERIALS FOR RENEWABLE ENERGY APPLICATIONS AT BUILDINGS

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Abstract— Nanotechnology has recently received increasing attention owing to its ability for enhancing the materials' features, improving efficiencies, and reducing sizes of devices. The contribution of energy devices based on nano phase change materials to energy conservations and worldwide gas emission degradation is of current interest. In this study, phase change materials developed for utilization in renewable energy implementations for constructions and the general thermo-physical features of these materials are investigated. In the light of these features, prominent parameters were determined.

Renewable Energy	With the support of professionals working on this subject, comparative evaluations of these parameters were made according to their importance in applications for renewable energy systems at buildings.

I. Introduction

The appropriateness of a phase change material for construction implementations is dependent on the incorporation's purpose (cooling/heating), the active or passive incorporation technic used, and the construction place [1-3]. In general, there are fewer publications dealing with phase change material heating applications than the ones with cooling applications [4]. This owes to the increased efficiency of the phase change materials in hot environments and good solar radiation [5, 6].

In recent decades, heat energy storage, which connects energy utilization and generation, has become a research focus. In particular, in renewable energy applications, latent thermal storage units utilizing phase change materials with isothermal functioning parameters and thermal energy storage densities are critical. A phase change material's melting temperature is a critical parameter that is related to the phase change material type and building location. High power storage densities in phase change materials allow them to store a considerable amount of thermal energy and give it up for next utilization at a comparatively stable heat. As a result, careful consideration should be given to the phase change material type and properties for effective and beneficial use [7, 8]. The phase change material heat power storage's integration of units with sun-based air mechanisms for building applications has been extensively researched [9, 10].

Researchers chose the appropriate phase change material type by analysing several phase change material candidates and selecting a specified candidate [11, 12] or the thermally best performing one depending on a few desired features, most of which were related to its thermo-physical properties [13, 14].

It was discovered that the inside heat efficiency of a residential utilization of a photovoltaic thermal-phase change material ceiling ventilation mechanism was excellent compared to that of a house that did not use phase change and photovoltaic heat materials for space heating. With solar thermal collectors, Ren et al. examined a coupled phase change material heat energy storage unit's thermal efficiency. The charging air-flow ratio of the phase change material and the phase change material type were discovered to be the most significant elements effecting the stored power in the thermal energy storage mechanisms [15]. For house space heating, Kumer and Waqas conducted a parametrical research of a phase change material-sourced sun-based air mechanisms. The air flow ratio, of the phase change material's mass, and the storage material's melting point were discovered to be the most responsive characteristics effecting the efficiency of the thermal energy storage [16]. Dolado et al. used a matrix of phase change material slabs' to characterize the phase change material heat power storage unit's performance. It was stated that optimizing the plate superficies' roughness, the air flow ratio, the air gap among the phase change material plates, the phase change material unit length, or the phase change material plate thickness can achieve the phase change material heat power storage unit's desired thermal transfer [17]. The optimal phase change material must be chosen for efficient and effective thermal storage in the heat energy storage unit. The optimal phase change material must be chosen for efficient and effective thermal storage in the heat energy storage unit.

In process research, multiple-attribute decision support system is developed as an arithmetical tool to help planners to apply nominative assessments [18]. In the mechanical engineering domain, the implementation of multiple-attribute decision support system algorithms is common. These multi-attribute decision support system methodologies are dependent on different theories like outranking, reference point, and binary benchmark process. Generally utilized multiple-attribute decision support system technics are MAUA, MOOSRA, COPRAS, PROMETHEE, CODAS, EDAS, MOORA, TOPSIS, and AHP [19]. With the help of MCDM techniques, analysis can be made for many areas of renewable energy. System selection for drying worthless-seeds [20], assessing power products for generating bio-based gas [21], optimum produce choice [22], and sorting sustainable power sources [23] are a few examples.

Multi-attribute decision support methods are progressively utilized in the material choosing issue. The necessary stages for material choosing operations are choosing and ranking the correct material for a specific implementation.

Regarding phase change materials, it has also been examined that researchers have used multi-attribute decision support system algorithms to choose the proper phase change material for low temperature implementations. Wang et al. (2015) utilized VIKOR as a multi-criteria decision-making method in selection of phase change materials [24]. Another study involving MCDM methodology in phase change material selection is conducted by Yang et al. (2018). When choosing a proper phase change product for a renewable energy system, strategic weight values for each of evaluative criteria must be estimated. However, the algorithm choice used in a given case is determined by the designer. According to scientific literature, numerous works have restricted their research plans to several algorithms with a restricted set of weight value prediction technics. Weight estimation techniques have either used a subjective or an objective weighting scheme [25].

This work's primary goal is to identify the best phase change material alternatives for integration to the construction of renewable energy mechanisms in buildings for energy efficiency. More than 46 recent research are investigated and analysed in order to demonstrate the contribution of phase change materials to construction heating power savings and to compare the phase change material alternatives' potency of using a sole qualitative decision-support matrix.

II. Methodology

Analytic hierarchical process methodology is used to calculate the nominative weight values for resolving multiple attributes difficulties. The optimum resolution is found pertaining to the importance of different attributes and options. The primary limitation is that, as the attributes' number and options raise, this strategy would be more complex. The processes to be followed in analytic hierarchical process methodology are given below:

Stage 1: Creating the hierarchic structure based on the phase change material alternatives and attributes.

In Table 1, selected thermo-physical features of the alternatives are given. The hierarchic structure in the first stage is created using the five attributes provided in Table. All thermo-physical attributes are treated as the main criteria.

Stage 2: Develop the binary comparison matrix in relation to relative significance.

Pairwise comparisons of the attributes in Table 1 using the scale provided in Table 2 result in relative importance values of these attributes.

The decision-matrix displayed in Table 3 is built using the pairwise comparison of the attributes. The table shows the relative importance values of the parameters utilized.

Table 1: The thermo-physical properties of phase change materials

Ref.	Phase Change Materials	Thermal Conductivitiy (W/mK)	Density (kg/m^3)	Specific Heat (J/kgK)	Latent heat of fusion (J/kg)	Melting Temperature (K)
[26]	Water	0.561	999.84	4.182 X10^3	334 X10^3	273.15
[27]	bio-based	0.2	860	-	149.2 X10^3	301.28
[28]	Paraffin	0.2699	900	2.95 X10^3	205.6 X10^3	331
[29]	Microencapsulated	0.31	961.4	2.13 X10^3	-	309.55
[30]	n-tricosane	0.2	796.9	156.7 X10^3	2.2 X10^5	329.15
[31]	C-L Acid material code [CO.14]	0.375	870.8	1.853 X10^3	100.1 X10^3	-
[32]	Liquid Cyclohexane	0.127	779	1.763 X10^3	32.5 X10^3	-
[33]	Nanoencapsulated n-octadecane	0.18	815	2 X10^3	244 X10^3	-
[34]	Nanosized lauric acid	0.147	1007	1.76 X10^3	211 X10^3	-
[35]	Paraffin RT44	0.2	780	2 X10^3	255 X10^3	316.15
[36]	Neopentyl-glycol PCM	0.25	1046	2.76 X10^3	131 X10^3	314.55
[37]	RT 21 PCM incorporated gypsum board	0.2	893	1.34 X10^3	34 X10^3	294.65
[37]	macro encapsulated SP-25 A8	0.6	1380	2.5 X10^3	180 X10^3	295.65
[38]	Li_2CO_3(35%), Na_2CO_3(65%)	1.89	2260	1.64X10^3	344 X10^3	778.15
[38]	Li_2CO, K_2CO_3, Na_2CO_3	2.02	2260	1.65 X10^3	276 X10^3	670.15

Table 2: Scale of comparison

Intensity	Explanation	Definition
9	The strongest potential order of affirmation can be found in the information supporting one attribute more than the other.	Extreme significance
7	One attribute is greatly preferred than other.	Demonstrated or strong significance
5	Judgment favours one attribute more than the other quite strongly.	Strong significance
3	Judgment favours one attribute slightly more than the other.	Moderate significance
1	The goal is equally benefited by both attributes.	Equal significance
2, 4, 6, 8	There are occasions when compromise is required.	Intermediate values

Table 3: Decision Matrix

Matrix	Thermal Conduct.	Density	Specific Heat	Latent heat of fusion	Melting Temp.	Criteria Weights
Thermal Conductivity	1	2	3	5	1	32.81%
Density	1/2	1	1/2	2	1/4	10.95%
Specific Heat	1/3	2	1	3	1/2	16.45%
Latent heat of fusion	1/5	1/2	1/3	1	1/5	592%
Melting Temperature	1	4	2	5	1	33.88%

For instance, the table indicates that *thermal conductivity* is twice as important as *density* and three times more important than *specific heat*. The last column in Table 3 is calculated based on these pairwise comparisons. Accordingly, the emerging relative priorities illustrated in Fig. 1; Thermal Conductivity and Melting Temperature are defined to be the attributes with the maximum contribution towards the attractiveness of the alternative materials.

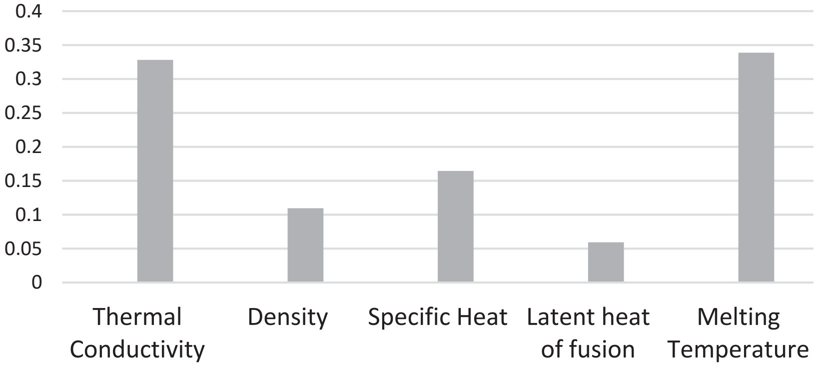

Figure 1: Relative weights of the criteria

Stage 3: Normalizing the thermo-physical values of the material alternatives for each attribute.

Fifteen phase change material alternatives were defined for the aim of this research. Table 1 contains a list of these alternatives as well as the values for each attribute.

Table 4 shows the values that are normalized. To obtain these normalized values, the values in the table are divided by the total of each row.

Stage 4: Creating the weighted matrix by multiplying the normalized values with the weight of each attribute calculated in the second stage.

The normalized values in Table 4 are then multiplied by the relative weight values of each of factors given in Table 3 to produce the weighted preferences of the options shown in Table 5.

Table 4: The priorities normalized

	Water	Bio-based	Paraffin	Micro-encapsulated	n-tricosane	C-L Acid material code	Liquid Cyclohexane	Nano-encapsulated n-octadecane	Nanosized lauric acid	Paraffin RT44	Neopentyl-glycol PCM	RT 21 PCM incorporated gypsum board	Maco encapsulated SP-25 A8	Li2CO3(35% Na2CO3(65	Li2CO3(32% K2CO3(35%) Na2CO3(33
Thermal Conducti-vity	0.075	0.027	0.036	0.041	0.027	0.050	0.017	0.024	0.020	0.027	0.033	0.027	0.080	0.251	0.268
Density	0.060	0.052	0.054	0.058	0.048	0.052	0.047	0.049	0.061	0.047	0.063	0.054	0.083	0.136	0.136
Specific Heat	0.023	0.000	0.016	0.011	0.846	0.010	0.010	0.011	0.010	0.011	0.015	0.007	0.013	0.009	0.009
Latent heat of fusion	0.123	0.055	0.076	0.000	0.081	0.037	0.012	0.090	0.078	0.094	0.048	0.013	0.066	0.127	0.102
Melting Temp.	0.065	0.072	0.079	0.073	0.078	0.000	0.000	0.000	0.000	0.075	0.075	0.070	0.070	0.185	0.159

Table 5: The alternatives' emerging scores

	Water	Bio-based	Paraffin	Micro-encapsulated	n-tricosane	C-L Acid material code	Liquid Cyclohexane	Nano-encapsulated n-octadecane	Nanosized lauric acid	Paraffin RT44	Neopentyl-glycol PCM	RT 21 PCM incorporated gypsum board	Maco encapsulated SP-25 A8	Li2CO3(35% Na2CO3(65	Li2CO3(32% K2CO3(35%) Na2CO3(33
Thermal Conduct	0.024	0.009	0.012	0.014	0.009	0.016	0.006	0.008	0.006	0.009	0.011	0.009	0.026	0.082	0.088
Density	-0.007	-0.006	-0.006	-0.006	-0.005	-0.006	-0.005	-0.005	-0.007	-0.005	-0.007	-0.006	-0.009	-0.015	-0.015
Specific Heat	0.004	0.000	0.003	0.002	0.139	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.001
Latent heat of fusion	0.007	0.003	0.004	0.000	0.005	0.002	0.001	0.005	0.005	0.006	0.003	0.001	0.004	0.007	0.006
Melting Temp.	0.022	0.024	0.027	0.025	0.026	0.000	0.000	0.000	0.000	0.025	0.025	0.024	0.024	0.063	0.054
Total Score	0.051	0.031	0.040	0.034	0.174	0.014	0.003	0.010	0.006	0.036	0.035	0.028	0.047	0.139	0.134

Each of the value in Table 5 is multiplied by the associated weight of each attribute. Consequently, the total of each column is calculated.

$$Score_j = W_i x\, A_{ij} \qquad (1)$$

where;
W_i: Weight of i*th* attribute
A_{ij}: Normalized value of j*th* material for i*th* attribute

The last row of Table 5 presents these weighted total scores. The results in Table 5 and Figure 2 indicate that n-tricosane has the maximum score (0.174) among other options.

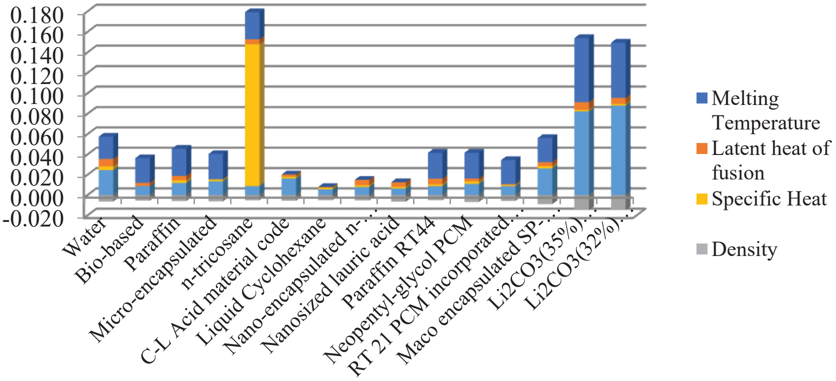

Figure 2: Relative scores

III. Conclusion

With their spectacular phase shifting ability, phase change materials hold the key for numerous breakthroughs in engineering and renewable energy systems for a sustainable future. The phase change materials, which release heat energy across a wide temperature ratio, have emerged as a leading choice for a wide variety of technical applications, including thermal, civil, electronics, and textile. Engineers are more and more interested in utilizing phase change materials for energy storage practices such as thermal, micro-electronic practices for cooling, space cooling or heating in modern constructions, and smart fabrics.

Multi-attribute decision support system methodologies can solve the most efficient material selection topics in renewable energy applications at buildings, and the methodology can be performed for other decision-making problems too. This research supplies a multi-attribute optimization approach for renewable energy mechanisms utilizing phase change materials for buildings. Among the investigated materials, n-tricosane is given the maximum score. It has been presented to the literature as a material that can be useful to evaluate in buildings.

To select the best phase change material candidate for future research, the matrix considers several thermos-physical and technical factors. The methodology used in this research is thought to supply a logical and excellent foundation for future research to easily and efficiently choose the most efficient phase change material type.

Suggested methodology can aid the decision-makers and planners in making stronger and informed decisions, particularly in phase change material selection in these types of implementations. On the other hand, further investigation is still needed to examine the potential and applicability of more multi-attribute decision support system methodologies to decrease the gap between the practice and theory.

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