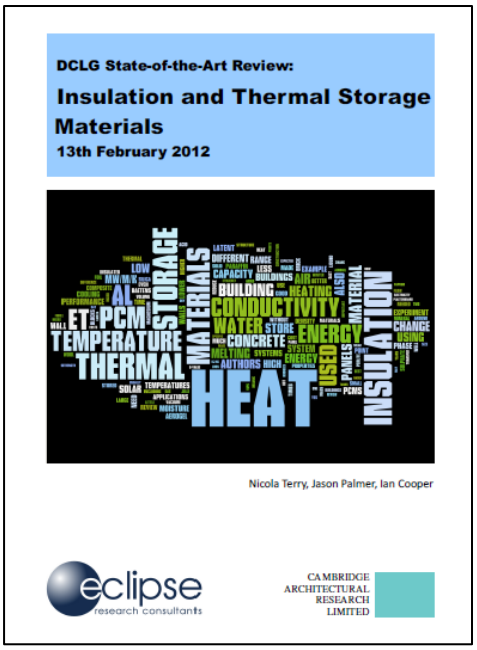
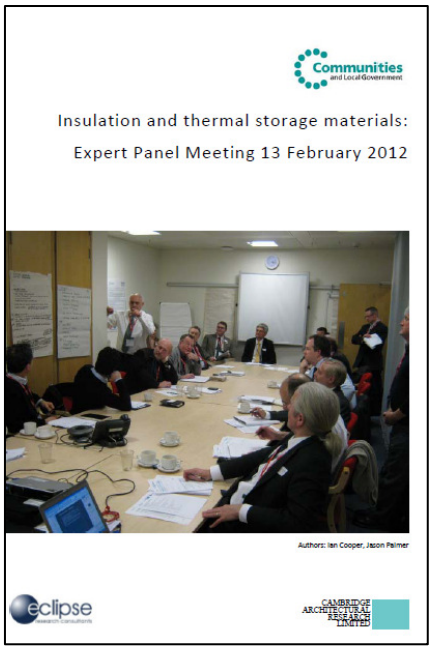
State-of-the-Art Review:
Insulation and Thermal Storage Materials

Overarching Summary





The Department of Communities and Local Government commissioned Cambridge Architectural Research and Eclipse Research Consultants to investigate insulation and thermal storage materials. There were two parts to the work: a comprehensive Literature Review, and an Expert Panel Meeting.

The **Literature Review** identified and searched through 100 of the most useful papers and other publications written recently about insulation and thermal storage. It summarised the key points and included searchable tables with the most important findings from each publication.

The **Expert Panel Meeting** assembled a group of experts representing a wide range of stakeholders with different backgrounds, experience and expertise. Twenty-one experts contributed to the meeting in total. CAR and Eclipse put specific questions to the panel and encouraged discussion between participants.

While the Literature Review largely drew attention to scientific work on insulation and thermal storage, the Expert Panel Meeting was more concerned with practical issues to do with how these materials are used in construction. The Literature Review was also necessarily restricted to what had been published, whereas there was more scope to consider specific issues of interest to the Department in the Panel Meeting. These differences make it extremely hard to draw out areas of consensus or disagreement between the Literature Review and the Expert Panel Meeting.

In essence, the **Literature Review** provided:

- quantitative data about the technical performance of thermal storage materials
- quantitative data about the technical performance of insulation materials
- some information about the limitations of both types of materials – for example, in terms of longevity/fragility of vaccuum insulated panels or phase change materials

Whereas the **Expert Panel Meeting** provided:

- a more subjective assessment of which of the materials was likely to make the most significant contribution to meeting climate change objectives over the next 5-10 years
- a measure of the perceived barriers in using these new materials in construction projects – notably linked to shortages in design and installation skills, robustness and durability on site, and cost and carbon impact

The Executive Summaries from our detailed reports from both parts of the work are reprinted below.

Literature Review

Thousands of publications have been written about thermal storage and insulation, even in just the past few years. Our literature search found more than 2000 sources on thermal storage published in the last four years, and more than 600 sources on thermal insulation.

The literature on **thermal storage** divides into three slices:

1. phase-change materials – which absorb heat when they melt from solid to liquid, and can add thermal capacity without affecting the heating response time
2. long-term heat storage – including inter-seasonal storage
3. short-term applications, including cooling

Experiments using **phase-change materials** (PCM) in plasterboard, aimed at reducing overheating, have been found to cut peak temperatures by 2-4°C. They can double the heat stored in some constructions. Up to 25 PCM can safely be included in plasterboard, or up to 5 percent in concrete.

Paraffin PCMs are the most commonly used in building applications – partly because they are economical, have good latent heat from 120-266 kJ/kg, and useful melting points from 20-112°C. (These figures are for commercial paraffins.) However, paraffins change volume on solidification and melting, which makes them prone to leaking. Fatty acids, 'oleochemical carbonates' (derived from animal and plant fats) could also be used in future, and salt hydrates (salts containing water of crystalisation) are already available commercially, but there are unresolved issues with all three at present.

Material	Phase change temperature	Latent heat
Paraffins	-57 to 112°C	120-266 kJ/kg
Fatty acids	30-70°C	150-220 kJ/kg
Oleochemical carbonates	-5.9-46.9°C	144-227 kJ/kg
Polyethylene glycols	10-55°C	108-176 kJ/kg
Inorganic PCMs	-31-117°C	126-251 kJ/kg

Both thermal capacity (how much heat can be stored) and thermal conductivity (how fast heat is absorbed or released) are important in thermal storage. While many PCMs have low thermal conductivity, this can be raised using additives or building small nodules in a large matrix.

PCM nodules have been tested in concrete floors, and allow the floors to be used as night storage heaters. Calcium chloride hexahydrate (a salt hydtrate with a melting temperature of 24°C), encapsulated in 75mm nodules, has been used like this.

It is very difficult to give cost estimates for PCMs because there are so many types and applications. However, the materials alone typically cost in the range from around £3 to £13 per kg. Encapsulation (to stop them melting and running away, and to improve conductivity) can double this cost, and micro-encapsulation (storing them as tiny particles in hard shells) doubles the cost again.

Special concretes and salts can provide **long-term storage** through a reversible chemical reaction such as dehydration and rehydration. However, water and gravel are more commonly used, and these give an energy density of 210 MJ/m^3 (58 kWh/m^3).

Refrigeration and air conditioning can draw on a cold reservoir for **short-term applications**. This can reduce the peak cooling demand and the peak load on the electricity grid. Again, PCMs can be used (sometimes in water), but there are special requirements – including stability over thousands of heating and cooling cycles.

The work on **insulation** is more focused around materials, and we scrutinised work on four sorts of materials:

1. natural insulation materials – e.g. mineral wool, cork, cellulose
2. new insulation materials – e.g. expanded polystyrene, polyeurethane, or aerogel
3. vacuum-insulated panels
4. multi-foils

Natural insulation materials perform at least 10 times better than brick or stone, see table. New insulation materials perform at least 20 times better than brick or stone, while vacuum insulated panels are better still, at least 60 times better than brick or stone. However, aerogel (the best-performing new insulation material), and vacuum-insulated panels, remain very expensive. There are also concerns about the longevity of vacuum-insulated panels, with some consensus that expected service life will be 10-40 years, although aluminium envelopes can increase this.

Material	Thermal Conductivity (W/mK)	Minimum improvement in conductivity over brick or stone	Indicative costs
Brick or stone	0.6-2.5	-	-
Natural insulation materials	0.03-0.05	20	£9-£18/m^2
Mineral insulation	0.03-0.04	20	£5/m^2
Petro-chemical insulation	0.02-0.04	30	£5-£22/m^2
Layered foil	0.033-0.035	18	£8-£9/m^2
Aerogel	0.013-0.014	42	£20-£30/m^2
Vacuum-insulated panels	0.004-0.01	60	£40-£50/m^2

Expert Panel Meeting

An Expert Panel Meeting was held for the Department of Communities and Local Government in February 2012. The aim of the meeting was to assemble participants from a wide range of backgrounds with experience and expertise, see Appendix 1, on physical and market limitations of thermal management materials and systems. The purpose of the meeting was to provide the Department with information to support its policy- and decision-making in this area.

Participants were asked which of the following types of thermal storage and insulation materials they thought would make the most substantive contribution to reducing energy consumption and CO2 emissions over the next 5 to 10 years.

Thermal storage materials/systems:

1. phase-change materials
2. long-term heat storage
3. short- term applications

Insulation materials:

1. natural insulation materials
2. new insulation materials
3. vacuum-insulated panels
4. multi-foils

Participants were asked to assess these against two sets of factors

- their technical and performance aspects
- barriers and incentives to their take-up

Their responses at the Expert Panel Meeting were collected in two stages: first, from individual participants captured on their response forms, and second, via group discussions. Both individually and jointly, participants were asked a) to identify which materials/systems would make the most substantive contributions over the next 5 to 10 years, and b) what they saw as the most significant issues likely to impact on these contributions.

Summary of results

Thermal storage materials/systems

In aggregate, participants saw phase-change materials as likely to make the most substantive contribution to reducing energy consumption and CO2 emissions over the next 5 to 10 years. But they saw phase-change materials as facing manifold barriers which may prevent them from doing so, especially since they saw few incentives currently working in their favour. And phase-change materials, while selected as the highest priority, were also identified as problematic because they were seen as having the most disadvantages and as raising the most concerns.

Insulation materials:

In aggregate, participants saw new insulation materials as likely to make the most contribution over the next 5 to 10 years. But they saw these materials as also facing manifold barriers that may

prevent them from doing so, especially since they only saw a few incentives currently working in their favour. New insulation materials, while selected as the highest priority, were also identified as having disadvantages and raising concerns.

Participants used two different types of criteria when making their assessments:

1. those relating to intrinsic characteristics of the materials/systems themselves
2. those extrinsic to the materials/systems and related to the circumstances in which they have to be deployed

The table below shows some of the most commonly recurring of these intrinsic and extrinsic characteristics drawn from comments made by participants on their individual response forms.

Intrinsic characteristics	Extrinsic characteristics
(Life cycle) energy performance	Installation issues, including: Design skills Site operative skills Availability of 'good practice' technical detailing
(Life cycle) carbon impact	
(Lifecycle) costs, including payback periods	
Moisture penetration	
Fire risk	Operational issues, including: Occupant awareness and understanding of materials/system and associated controls Reliability and maintenance requirements
Acoustic properties	
Handleability	
Robustness/durability/delicacy	Operational environment conditions, including: Modelling/certification requirements arising from legislation such as Building Regulations Rules associated with Government and non-governmental schemes such as the Green Deal or NHBC Investors' perceptions of benefits, incentives and disadvantages
Longevity/decremental decay	
Toxicity	

This table indicates the highly complex nature of the judgements that participants made when they sought to prioritise and comment on the thermal storage and insulation materials under discussion. Doing so required them not just to consider such materials/systems against a wide range of divergent characteristics, but to seek to weigh these against each other in order to estimate which would be likely to make the largest contributions.

These assessments often have the quality of personal judgement calls since, as participants themselves conceded, the empirical evidence on which to base them – for instance, about longevity or about the performance of materials in situ, about the savings arising from their effective installation or about their operation in practice – are frequently absent or unknown to them.

What is remarkable is that participants still felt able, by drawing on their own diverse experiences and expertise, to prioritise the materials under consideration despite the lack of the empirical evidence that they see as necessary for attempting to do so. However, these personal judgement calls by participants do not constitute a robust basis for government policy- and decision-making.

Recommendations

An underlying purpose of the Expert Panel Meeting was to provide the Department with access to experience and expertise that could inform its decision-making on thermal storage and insulation. The meeting sends a clear message here to the Department on this front. If such decision-making is to be evidence-based, then as the table above indicates, that evidence has to cover a wide range of both intrinsic and extrinsic factors.

It has to include not just a variety of performance characteristics of the materials/systems in question but also a whole range of characteristics of the situations in which they will have to be deployed. To use the words employed by some of the participants, the Department's approach to decision-making here should be both 'holistic' and 'systems'-based. The evidence collected cannot be constrained to modelling or lab tests of the performance of the materials themselves. It should instead be extended to monitoring and evaluating their performance in built and occupied examples, across both new build and retrofitting situations.