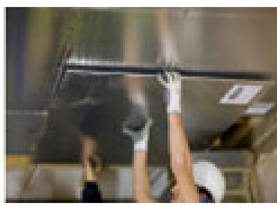
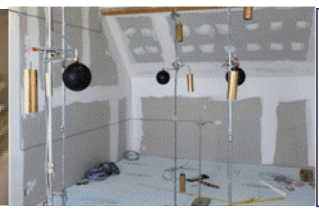
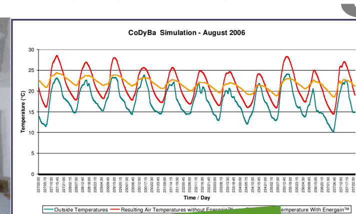
DuPont™
Energain®

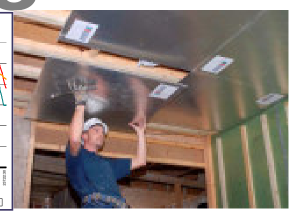
Phase Change Materials

New thermal mass solution for low inertia buildings









PASSIVE ROOM CLIMATE AND ENERGY MANAGEMENT

DuPont™ Energain® PCM guidebook
Edition: December 2010

C O N T E N T

1. Introduction

Buildings of all sizes and dimensions are at the mercy of solar gains, temperature fluctuations and the effects of internal heat sources, such as humans and electrical equipment.

Entering a traditional building with thick massive walls on a warm summer's day, one will recognise immediately the effect of thermal mass on room climate. Even in the afternoon, temperatures remains comfortable but in a low inertia building this comfort can typically only be maintained through active cooling with the cost of energy consumption and CO_2 output.

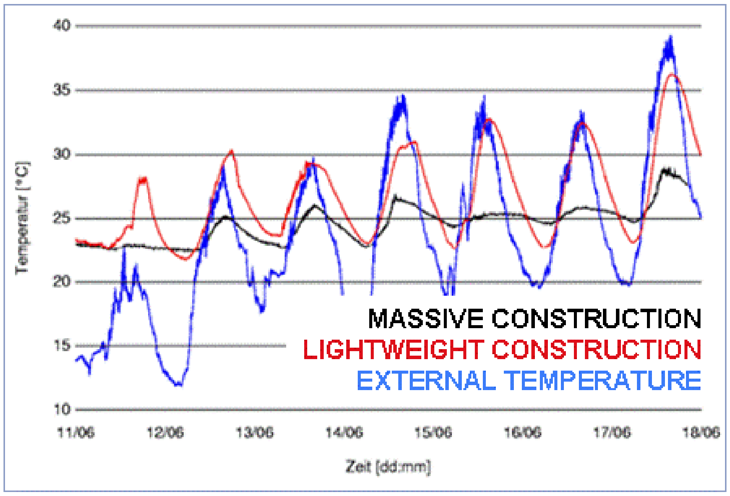


Diagram 1
Room temperature comparison of massive and lightweight construction under equal external conditions

Source
Fraunhofer ISE, Germany

Buildings in Europe represent 40% of the total energy consumption in the region. Heating and cooling represents the largest component of energy use, accounting for approximately 70 %[1]. Opportunities to reduce the heating and cooling demand in buildings therefore represent a potentially significant part of the future energy and CO_2 emission savings.

Adding thermal mass to low inertia buildings helps to enable a stable room climate by reducing typical temperature fluctuations and as a result reducing energy consumption for heating/cooling. Consequently, it combines the advantages of low inertia buildings (lower investment, short construction time, high flexibility) with a room climate generally experienced in traditional construction with no extra energy costs.

We are all responsible for environmental protection through how we live, how we behave and how we consume.

DuPont™ Energain® thermal mass panel can help to significantly reduce the CO_2 footprint of your building by reducing the energy consumption through passive room climate management.

[1] European Energy Portal, http://www.energy.eu/

1.1. Thermal mass definition

Thermal mass, often also referred to as thermal inertia is the ability of a material to absorb and store heat. The thermal mass performance is determined by thermal conductivity and high specific heat capacity to maximise the heat that can be stored per kg material.

Traditional thermal mass materials include concrete and masonry while Phase Change Materials as for example DuPont™ Energain® represent a new generation of thermal mass with an extraordinary high heat storage capacity.

1.2. Thermal mass in comparison

The higher the heat storage capacity of the thermal mass material the more excessive heat it can absorb and store per kg mass and so contribute to room climate. DuPont™ Energain® panels with a thickness of 5.26 mm absorb heat up to 515 KJ/m^2 at 18-24°C.

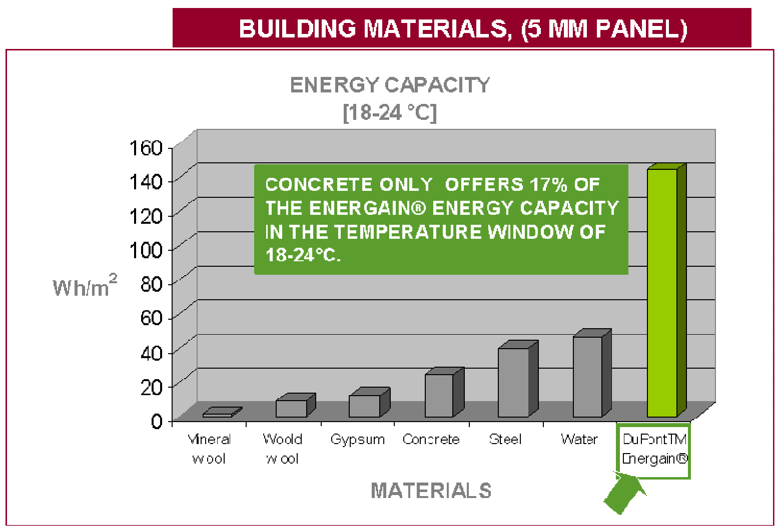


Diagram 2
Heat storage capacity in comparison

Source
Joseph Virgone, Lyon University, France

Its high heat storage capacity not only helps to stabilise the effects on room temperature by up to 7°C but also to reduce heating consumption up to 15% and air conditioning costs by up to 35%.

According to a study conducted by Joseph Virgone, Lyon University, France, to determine the optimum thickness/energy capacity ratio, 10 mm of DuPont™ Energain® has a comparable thermal mass capacity to 80 mm concrete. An increased thickness above these values does not result in a significant gain of energy capacity. In fact the limitation comes from the thermal diffusivity. This property measures the rate at which a temperature disturbance at one point in a body travels to another point. Materials with low thermal conductivity and high thermal capacity will have a low depth of penetration.

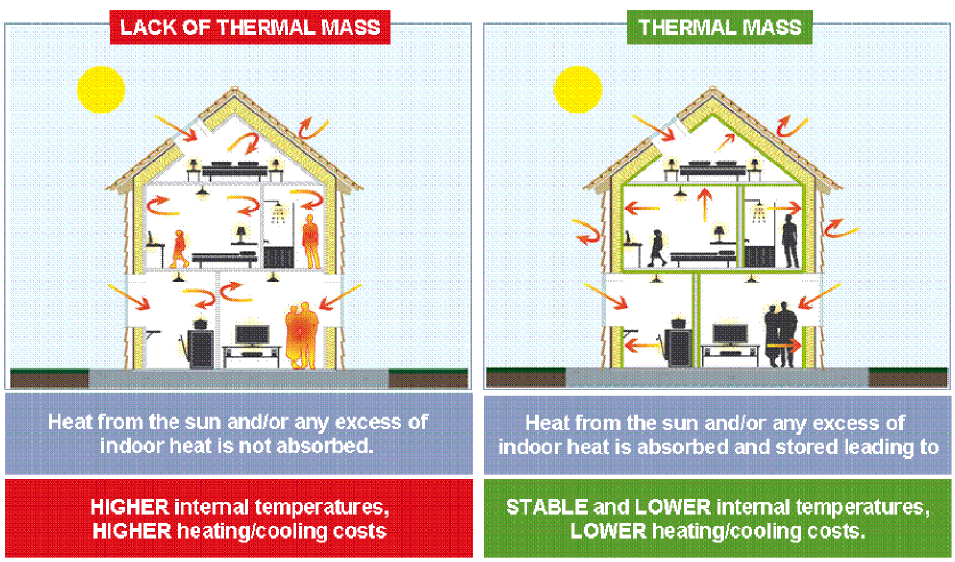
Phase Change Materials are able to absorb, store and release large amounts of heat or cold at comparatively small temperature changes by altering their physical state, as for example from solid to liquid. The advantage of Phase Change Materials is that they can store heat energy in a latent as well as sensible manner leading to a greater heat storage capacity per unit volume than that of conventional materials such as concrete.

1.3. Why thermal mass is important

Thermal mass helps to provide comfortable room temperatures and minimizing temperature peaks during warm summer days with no extra energy costs whilst on cooler days, it can help reduce heating energy.

Thermal mass contributes as a passive system to room climate management.

Cooling: During warm weather days, thermal mass absorbs excessive heat caused by solar gains, occupancy or internal heat sources as for example electrical equipment during the day. With the natural decrease of ambient temperature in the evening/night hours, the stored heat is released, enabling a new cycle the following day.
Heating: Solar gains through windows and internal heat is absorbed and then released in evening and night hours reducing the heating requirements.



1.4. Conditions for optimum use of thermal mass in building

The optimum use of thermal mass in room climate management of a building requires an integrated construction including a balance of building orientation, windows, thermal insulation, room usage, ventilation and shading just to name a few.

Orientation, windows and shading are considered as the three most critical building parameters in determining the impact of thermal mass to room climate.

Furthermore, the positioning of thermal mass significantly impacts the effect. Only the building materials on the inside of a room can contribute to the thermal mass effect,

therefore building materials with high thermal mass capacity should be facing the room.
What does this mean in practice? For example, materials like concrete have a high thermal mass capacity vs. insulation materials or wood. If insulation is applied on the inside of a concrete wall, it will remove any useful thermal capacity from the wall.

The best place to install PCM is in the ceiling, then in the walls, and finally in the floor.

1.5. Thermal mass complements thermal insulation

Very often, the question is raised, whether excellent insulation can compensate for lack of thermal mass or make it redundant.

Insulation materials by their nature cannot act as thermal mass as they typically have low thermal conductivity (the lower the conductivity, the better the insulation performance).
Thermal mass materials however, are determined by thermal conductivity and high specific heat capacity to maximise the heat that can be stored per kg material.

Both, thermal insulation and thermal mass complement each other. While thermal insulation minimises the heat/cold transfer through the building envelope between the building and the environment, thermal mass absorbs internal heat loads caused by solar gains, occupancy, electrical equipment or external heat loads that penetrate the building envelope through insulation for example.

DuPont™ Energain® phase change material at Busipolis building twice awarded for its excellent energy performance

The building of the SARL Busipolis company, in Metz (France) has received two awards for its excellent energy performance, one from the « Prebat » competition for Lorraine region and the other from the « Lorraine Qualité Environnementale » (http://lqe.fr). This office building (1950 sqm) has a total energy consumption of 38 kwh/sqm per year.

2. Phase Change Material – The new thermal mass generation

Phase Change Materials (PCMs) offer a higher heat storage capacity than many other conventional materials already at small temperature intervals. In the temperature window of 18 – 24℃, the heat storage capacity of 1 m^3 Energain® equals to 6 m^3 concrete.

2.1. Phase Change Material definition

PCMs, Phase Change Materials, such as water, paraffin, salt hydrates, etc. are all able to absorb, store and release large amounts of heat or cold at comparatively small temperature change by changing their physical state, as for example from solid to liquid, solid to solid or through evaporation of the storage material. The heat stored is called latent heat, therefore materials are also referred to as "LATENT HEAT STORAGE MATERIAL".

PCMs with a solid-liquid phase change are most commonly used, also in construction and building applications.

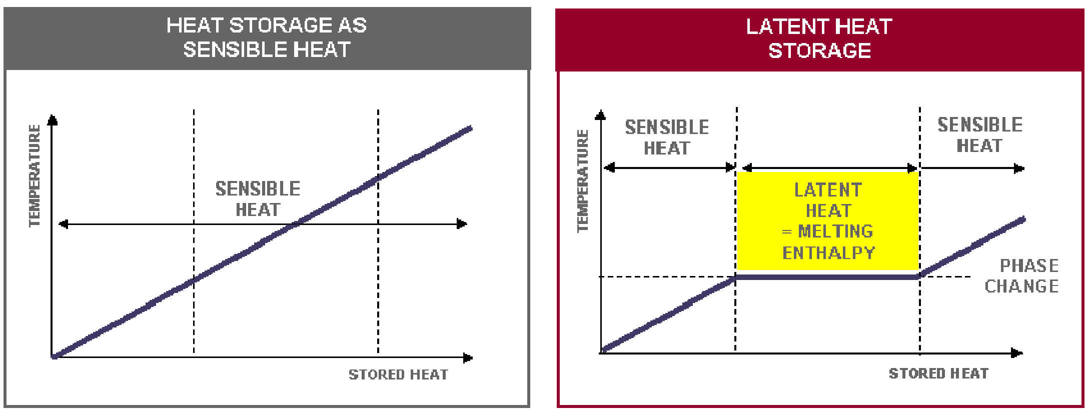


Diagram 3 *Heat storage principles,* ***Source*** *ZAE Bayern, Germany*

It's as simple as the ice cube melting in your drink: When ice cubes melt in a drink, they absorb heat from their environment without increasing their temperature and so keeping the drink cool.

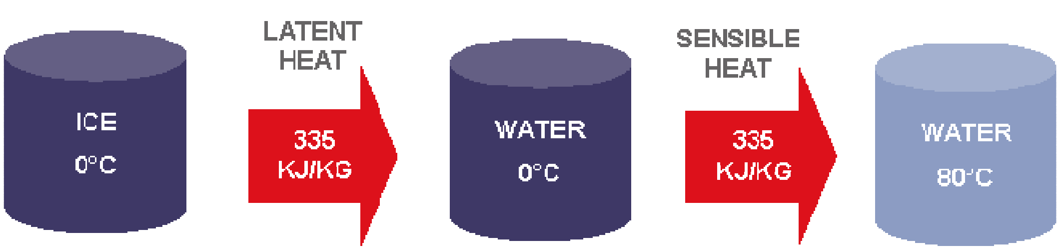


Diagram 3 *Heat storage principles,* ***Source*** *ZAE Bayern, Germany*

2.2. Phase Change Material technologies

PCMs can be differentiated by their encapsulation technology.

Macro-encapsulation was used in early development. Large volume of PCM was poured in containers like dimple sheets or small bags. This technology has the disadvantage to let the container leak, if perforated.

Micro-encapsulation on the other hand showed no such problem. It allows the PCMs to be incorporated into construction carrier materials, such as concrete, easily and economically. By coating micronised PCM with a protective coating, the particles can be mixed within a continuous phase such as plaster. Any damage to a micro bead of encapsulated PCM, may release only a very small amount of wax.

Molecular-encapsulation is another technology, developed by DuPont de Nemours. It allows a very high concentration of PCM within a polymer compound. The polymer molecules have been designed to “connect” to the wax molecules, creating therefore a homogenous compound. Molecular-encapsulation allows drilling and cutting through the material without any PCM leakage.

2.3. Phase Change Material (PCM) functionality in buildings

Heat inside the building is caused either by internal heat loads such as occupancy, electrical equipment, solar gains and external heat loads such as heat coming through the insulation of the building envelope. Installed as thermal mass between insulation and the plasterboard, Energain® enables passive room climate management by absorbing heat through melting.

The ***diagram 4*** shows the effect of installing a 5 mm Energain® panel combined with different thickness of glass wool insulation. The comparative factor is the resulting temperature in the attic.

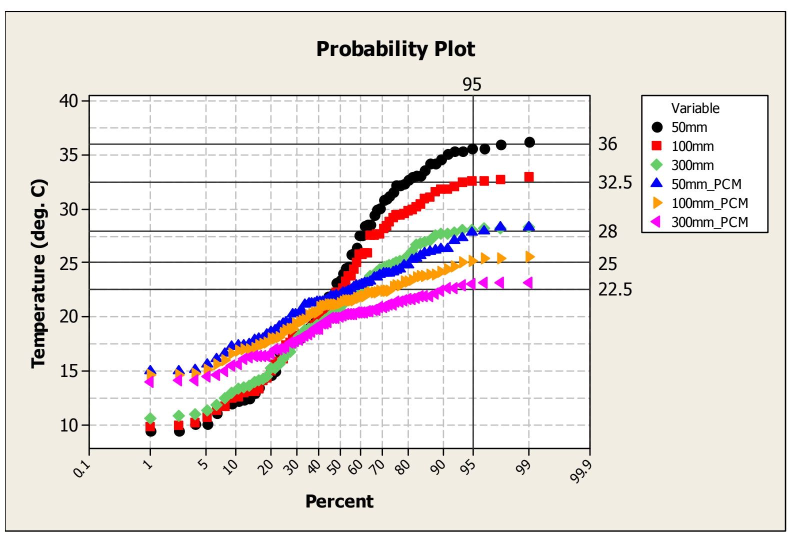
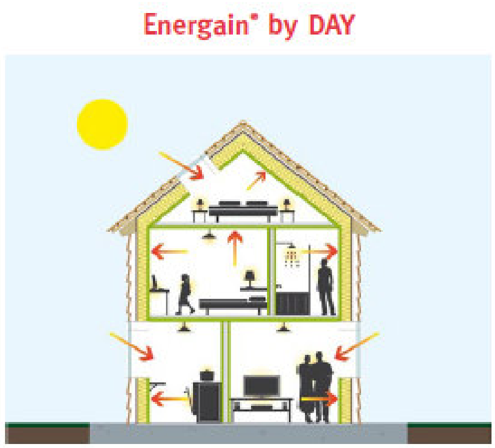


Diagram 4 *Dynamic vs. Traditional insulation impact on internal attic temperature,* ***Source*** *DuPont simulation*

To ensure a full functionality of PCM, it is critical that the ambient temperature drops to at least the minimum PCM solidification temperature point. Only a complete solidification allows a maximum heat storage capacity. This can be achieved through ventilation, both natural or mechanical, as well as defining and setting appropriate temperatures for the air conditioning system. Beside ventilation or air conditioning, it is also possible to use active (water cooled) surfaces, in case the building has been equipped with a floor or ceiling heating surface.

What happens if the PCM does not completely solidify? If the panel does not completely solidify, it will affect the efficiency in proportion to the degree that it has solidified. For example, think of a sponge, which is already half-absorbed with water: if the sponge is only half dry, then it can only absorb half the amount of water.



2.4 PCM performance advantages vs. incumbent building materials

PCMs, offering high heat storage capacity, have proven as reliable thermal mass in extensive market research throughout Europe by manufacturers and independent research institutes of repute like Fraunhofer Institut and ZAE Bayern in Germany, Lyon University in France just to name a few.

In a temperature window of 18°-24°C, a PCM as for example DuPont™ Energain® can store significantly more energy per volume as is typically stored by conventional building material like concrete, gypsum or wood wool with linear heat absorption as temperature increases.

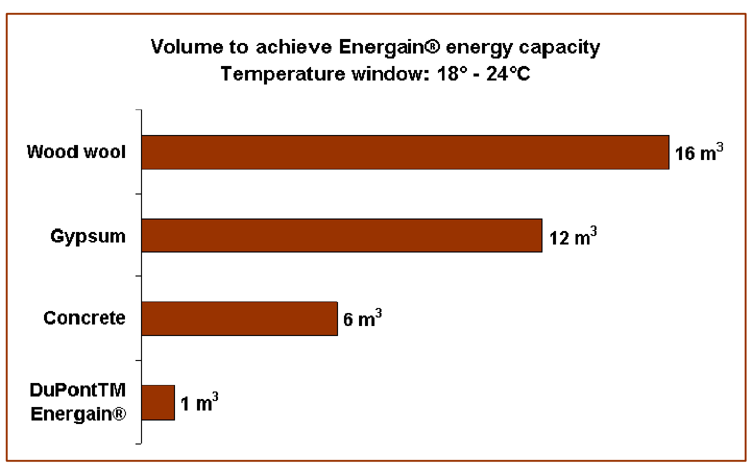


***Diagram 5** Heat storage capacity,*
***Source** Energy capacity analysis of building materials by Lyon University, France*

3. DuPont™ Energain® thermal mass solution based on PCM technology

DuPont Building Innovations has developed the Energain® panel to respond to the thermal mass needs of a variety of applications: the fast growing lightweight construction, low inertia buildings, internal insulation renovation projects, attics, etc.

3.1. Product introduction

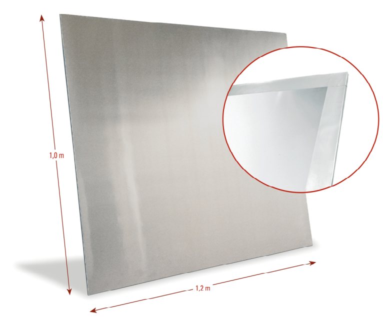
The DuPont™ Energain® thermal mass panel is laminated to aluminium protective foils, the core material is a mix of a copolymer and a paraffin wax 'phase change' material, which provides the panel's functionality.

DuPont innovation
DuPont holds a patent that ensures that the material (polymer compound/panel) maintains its mechanical and dimensional sustainability while the paraffin is in liquid state.

How does the panel function?
DuPont™ Energain® consists of a compound containing a Phase Change Material (PCM) of paraffin wax. At temperatures below 18 °C, the wax remains in a solidified state. Once the temperature inside a room reaches 22°C, due to solar gains and/or external temperatures, the phase change takes place and the paraffin wax melts. It is this phase change that absorbs the heat from a room into the DuPont™ Energain® panels. Conversely, as the internal temperature cools, reaching a temperature of 18°C, the paraffin wax re-solidifies, releasing stored heat back into the internal environment, as it does so.

Some key technical data

Thickness	5.26 mm
Width	1 m
Length	1.2 m
Area weight	4.5 kg/m^2
Melting point	21.7 °C
Heat storage	515 kJ/m^2 (18 -24°C)



3.2. Product installation

DuPont™ Energain® panels (1 m x 1.2 m x 5.26 mm, 5.4 kg) are safe to handle and do not contain toxic substances. The panels simply contain paraffin wax, a copolymer and aluminium and can therefore be handled without posing any special toxic safety precautions.

The panels can be installed on partition and interior walls, ceilings or exterior walls (from inside) and are fitted behind ordinary dry lining plasterboards. Cutting to any size possible, a sharp cutting instrument is recommended. Before installing the panels on a wall, each cut edge or abrasion to the aluminium should be closed with the aluminium tape. The panel can be fitted in place by drilling and screwing, nailing and stapling.

Using DuPont™ Energain® as vapour control layer – the panel is vapour tight, and can be used as a vapour control layer if the joins of panels are taped to ensure vapour tightness of the installed system.

DuPont™ Energain® must be installed preferentially in direct contact with the plasterboard in order to optimize the heat transfer toward the room. However when there is a utility cavity, DuPont™ Energain® can be installed on the opposite side of the plasterboard. In that particular case, it is necessary to cover DuPont™ Energain® with a vapour control layer in order to avoid that its low emissive surface reduces the heat transfer through the air gap.

Detailed installation information is available at http://www.energain.co.uk.

3.3. Product life-time

An accelerated aging test indicates that DuPont™ Energain® panels will be reliable for a long period of time and will not deteriorate in functionality, over the course of this time. The ingredients of DuPont™ Energain® are known to be stable over time.

3.4. Fire protection

In case of a fire, temperature can reach up to 700℃ in the first fifteen minutes and then can rise up to 1100℃. Product behaviour such as ignition, surface spread, smoking and dripping are critical when fighting the fire.

DuPont has carried out a series of fire performance testing at independent notified bodies including BRE Certification Ltd., United Kingdom and MFP Leipzig GmbH, Germany.

Test method	Description	Product classification
BS EN ISO 11925-2	Surface and edge exposure, 30 s flame application time each	Class E BS EN 13501-1:2003
BS 476 part 7	Method of test to determine the classification of the surface spread of flame of products; Energain® installed behind plasterboard, Energain® stand alone	Class 1
DIN EN 1364-1:1999	Fire resistance tests for non-loadbearing elements.	EI 60 EI 90 BS EN 13501-2:2003

Test reports are available at http://www.energain.co.uk.

DuPont™ Energain® adds thermal mass to the sustainable design of "Crossway" *by Architect Richard Hawkes*

Photos: Courtesy of Richard Hawkes

4. How Phase Change Material can contribute to room climate and energy management

Room temperature is one of the key determining parameters of room climate and plays a major role when it comes to human performance and concentration.

4.1. Room climate definition and why it is important

The human being's perception of room climate and comfort is determined by various physical conditions such as air temperature, relative humidity, air flow and surrounding wall temperature. Physiological criteria e.g. age, gender etc, can also play a part in this. Intermediary conditions such as clothing, level of activity, occupancy etc taken independently or in conjunction with these physiological criteria can also serve to contribute to this perception.

Room temperature is considered a dominating factor on room climate. It can be influenced by occupancy through people, use of equipment, lighting, solar gains through windows and thermal insulation performance as part of the building envelope.
Beside window orientation and surface materials, window solar penetration index, shading and ventilation, thermal mass, with its ability to absorb and store heat, represents a complementary option of passive room climate management.

Room temperature is not only important for the perception of comfort or physical well-being, it also plays a major role when considering human performance and/or concentration as shown in ***diagram 6***.

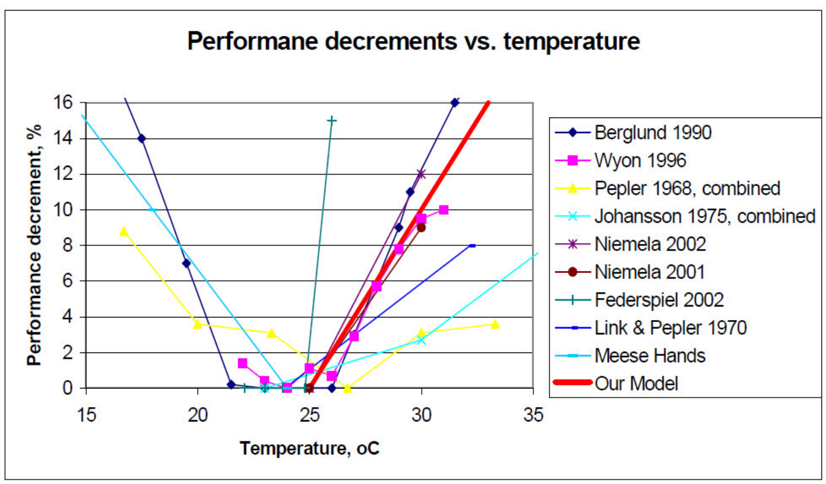


Diagram 6 *Human performance decrement in relation to temperature*[2]

[2] Olli Seppänen, Williman J. Fisher David Faulkner: Control of temperature for health and productivity in offices, summary of various studies

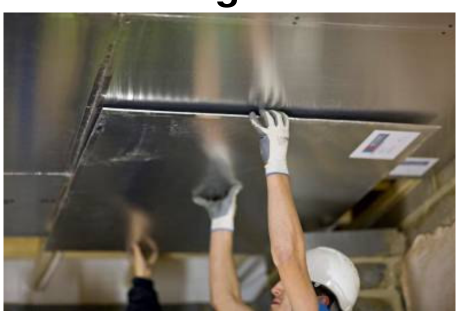
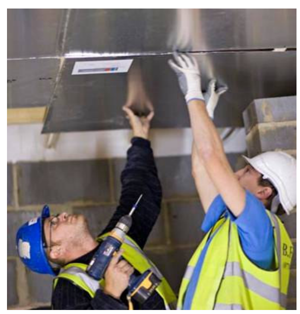
4.2. Legislative room climate requirements

Legislation supports reasonable room temperature management.

Example: UK

Indoor workplaces[3]	Minimum/Maximum temperature in the workplace are detailed in the “”Workplace (Health, Safety and Welfare) Regulations 1992” and states that “During working hours, the temperature in all workplaces inside buildings shall be reasonable”
School buildings[4] Document: BB-101	The performance standards for summertime overheating in compliance with Approved document L2 for teaching and learning areas are: a) There should be no more than 120 hours when the air temperature in the classroom rises above 28℃ b) The average internal to external temperature difference should not exceed 5℃ (i.e. the internal air temperature should be no more than 5℃ above the external air temperature on average) c) The internal air temperature when the space is occupied should not exceed 32℃. In order to show that the proposed school will not suffer overheating two of these three criteria must be met.

Hamond High School

Photos: Jake Fitzjones for DuPont

DuPont™ Energain® allows RMJM and Balfour Beatty to add high-tech thermal mass to the new Edinburgh Napier university campus


Images courtesy of RMJM and ENU

[3] Health and Safety Executive UK, http://www.hse.gov.uk
[4] Building Bulletin 101, Ventilation of School Buildings, Version 1.4, July 2006

4.3. Lightweight construction

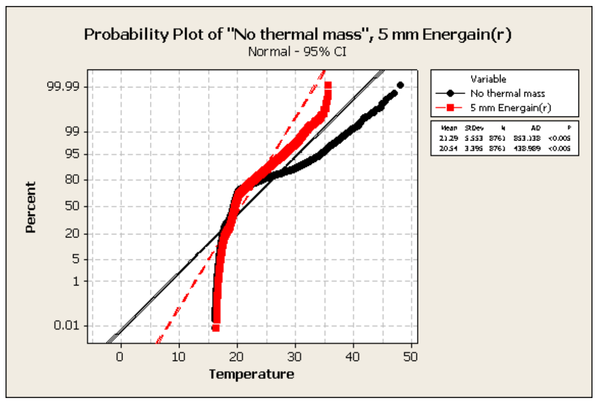
In structures with a low thermal mass, as for example in lightweight constructions, temperature fluctuations are much higher than in massive constructions and are typically offset by the use of air conditioning or alternative heating or cooling systems which may result not only in higher operational costs but also higher CO_2 emissions.

Thermal mass can help you to maintain comfortable temperatures in lightweight constructions <= 26℃. ***Diagram 7*** demonstrates a comparison between the probability simulation of temperatures reaching <=26% for a standard lightweight modular building with no thermal mass and one with DuPont™ Energain® as thermal mass in conditions that reflect the moderate Western European climate zone.

DuPont™ Energain® thermal mass panel, installed in the ceiling only, enables the room temperature to be maintained at <= 26℃ for 95% of the year. Without thermal mass, this temperature can only be maintained 80% of the year.

Diagram 7
Temperature probability plot for no thermal mass and 5 mm Energain®
TOTAL YEAR

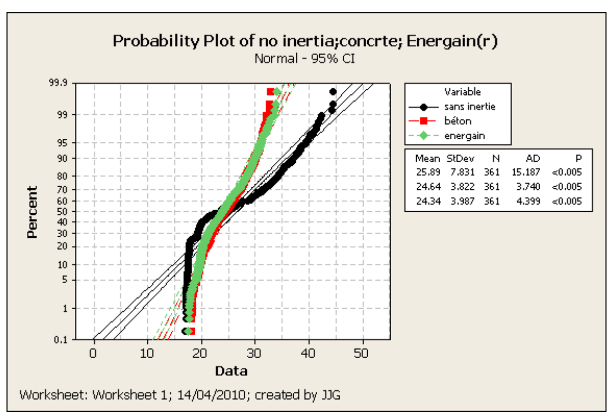
Source
DuPont



Looking at the summer period only, the effect of thermal mass is especially significant. As demonstrated in ***diagram 8*** showing three weeks in June (week 22-24), inertia allows staying below 26℃ for ~80% of the time. If no inertia applied, temperature will only stay 60% of time below 26℃.

Diagram 8
Temperature probability plot for no thermal mass and 5 mm Energain®
SUMMER PERIOD

Source
DuPont



4.4. Loft applications

The roof of a building not only needs to protect against cold, wind and rain but also against heat. If insufficiently insulated, a roof can quickly become a source of energy loss or heat gain of the building.

During hot summer days, the external roof temperature can reach up to 85°C[5] with the majority of the heat blocked by the tiles. However, some heat may penetrate this layer and warm up the attic and rooms underneath depending on insulation product and/or thickness for example.

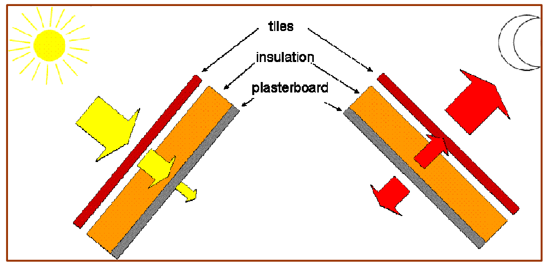


Diagram 9 *Traditional insulation*
Source *DuPont*

As shown in ***diagrams 9 and 10***, the applied insulation can significantly impact attic temperature.

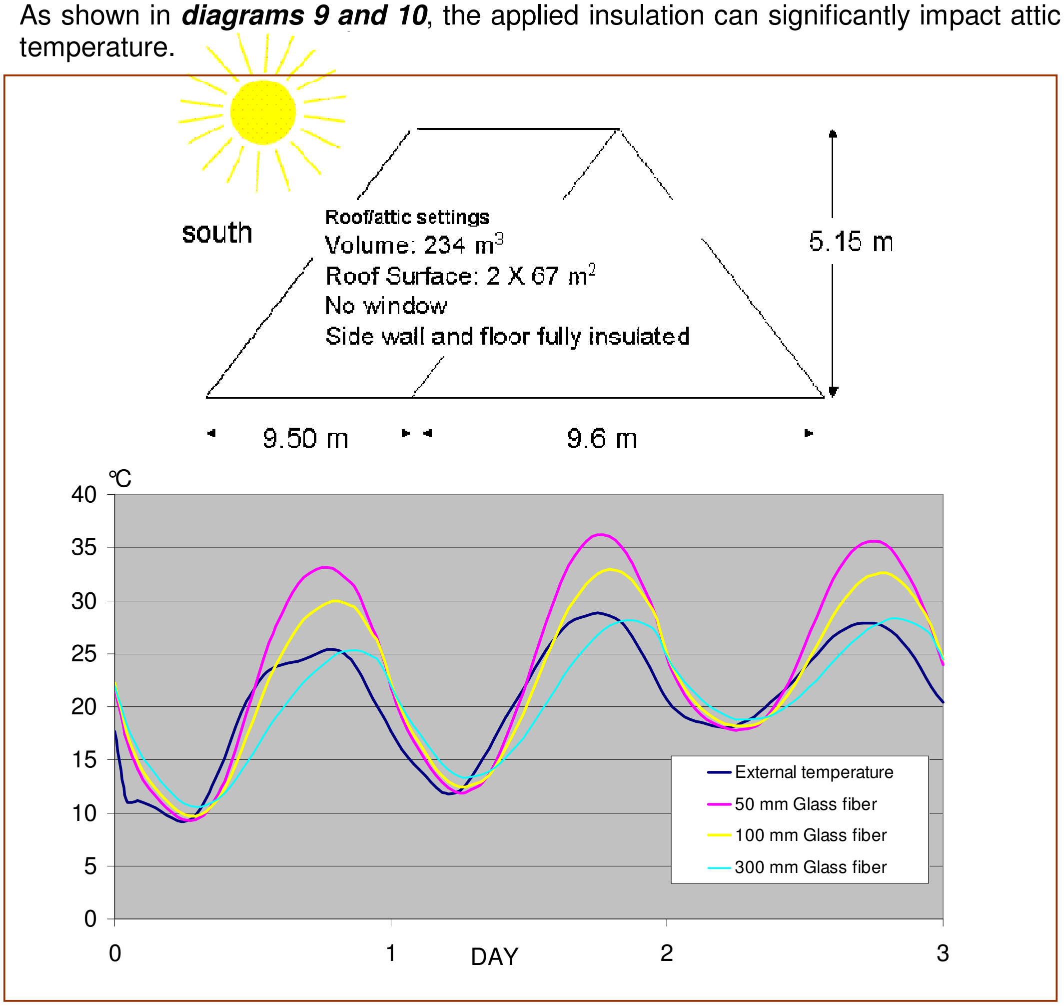


Diagram 10 *Insulation thickness influence on internal attic temperature,* ***Source*** *DuPont simulation*

[5] K. Liersch: Belüftete Dach- und Wandkonstruktionen, Band 3 – Dächer, Bauphysikalische Grundlagen des Wärme- und Feuchteschutzes

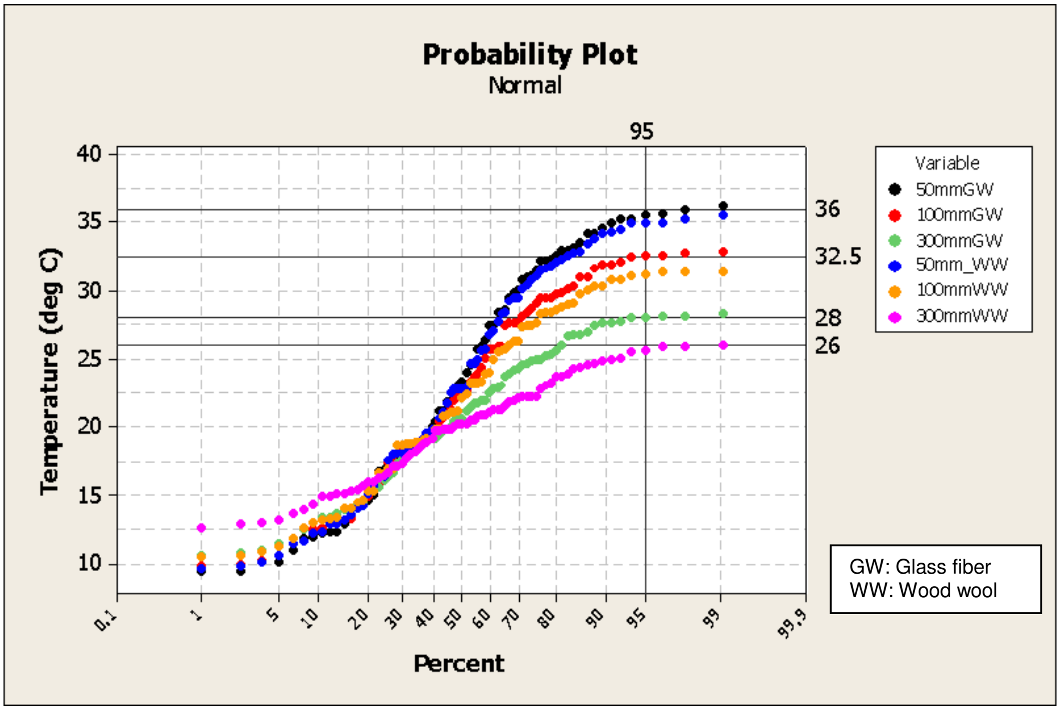


Diagram 11 *Probability plot for internal temperature reach by insulation type and thickness*
Source *DuPont simulation*

But even with excellent insulation, temperature can raise far above acceptable room climate. Creating a dynamic insulating system through the combination of traditional insulation products with DuPont™ Energain® thermal mass panel can significantly improve your room climate during the summer months as shown in ***diagram 14***.

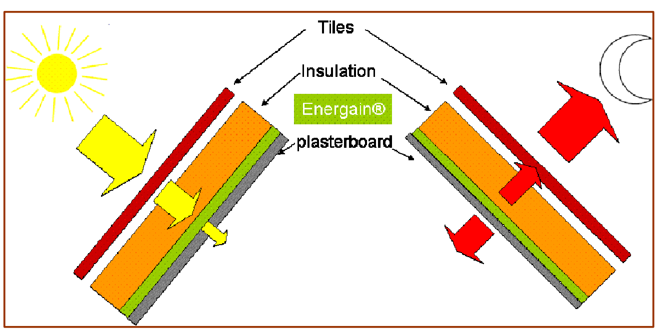


Diagram 12 *Dynamic insulation*
Source *DuPont*

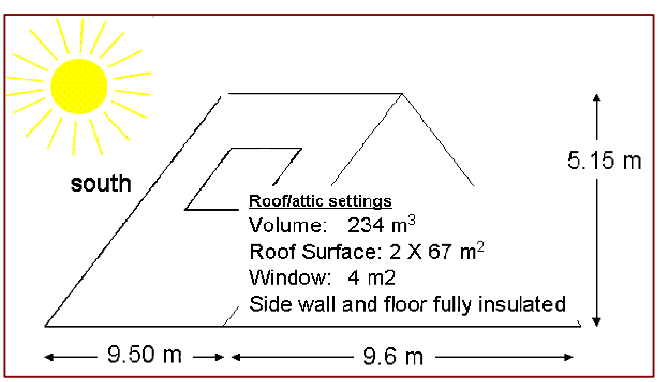


Diagram 13 *Simulation settings*
Source *DuPont*

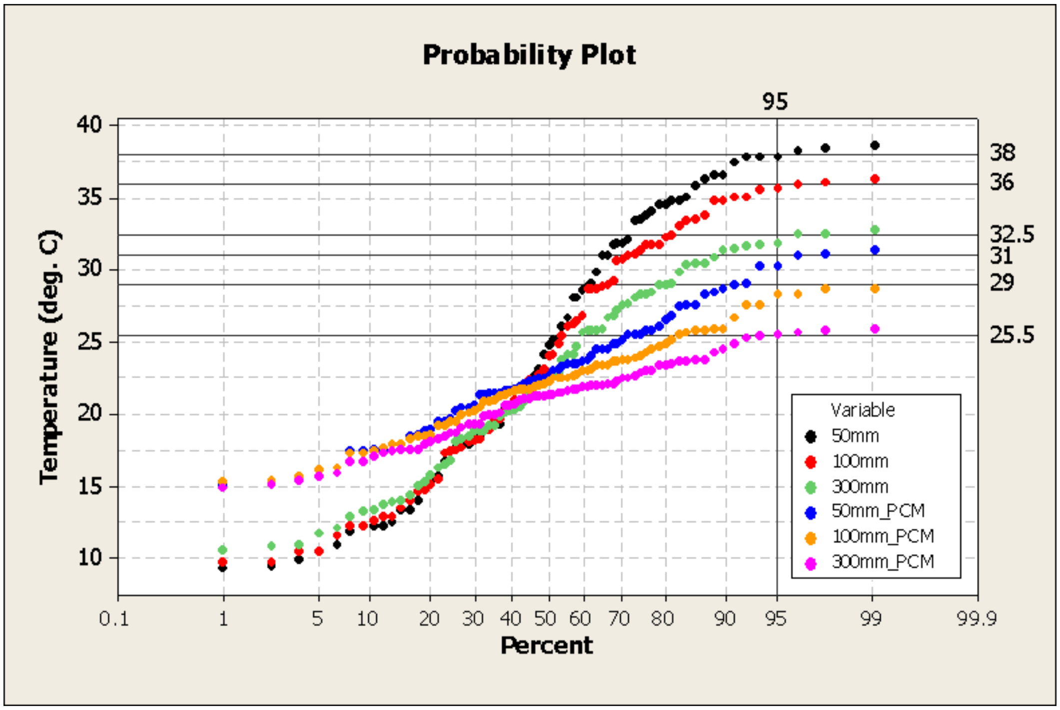
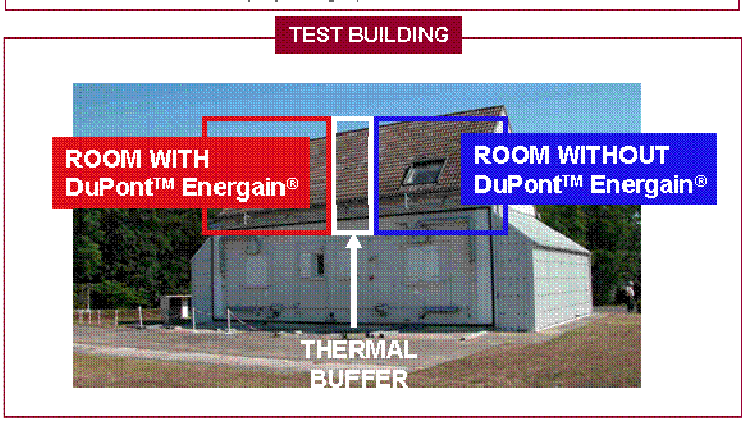


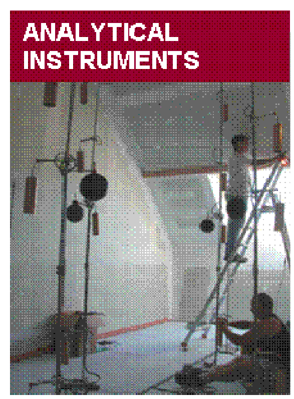
***Diagram 14** Dynamic vs. Traditional insulation impact on internal attic temperature, **Source** DuPont simulation*

To prove the performance of Energain®, DuPont has conducted a real life experiment with EDF France over a period of 8-9 months covering different seasons in a moderate climate zone (Paris region):

Test duration: August 2006 – April 2007
DuPont™ Energain® has been tested in the attic.

Insulation in attic:
R =5 m²K / W
Ventilation:
Summer : 0.5 vol/h (day), 2.4 vol/h (night) – free cooling
Winter : 0.5 vol/h (day & night)





The experiment has not only proven the product's performance/functionality in real life applications, but also confirmed the accuracy of building.

5. How to specify Phase Change material as Thermal Mass Solution

As a starting point, one can estimate the effect of DuPont™ Energain® by comparing with concrete. In a basic approximation, 5 mm of DuPont™ Energain® can be compared to 3 - 4cm of concrete. (depending on the climate conditions).
The quantity needed is generally following the simple rule of thumb: minimum 0.5-1 m^2 per m^3 room volume. Although these basic rules allow to get started, it is highly recommended to design the solution with a dynamic software suite.

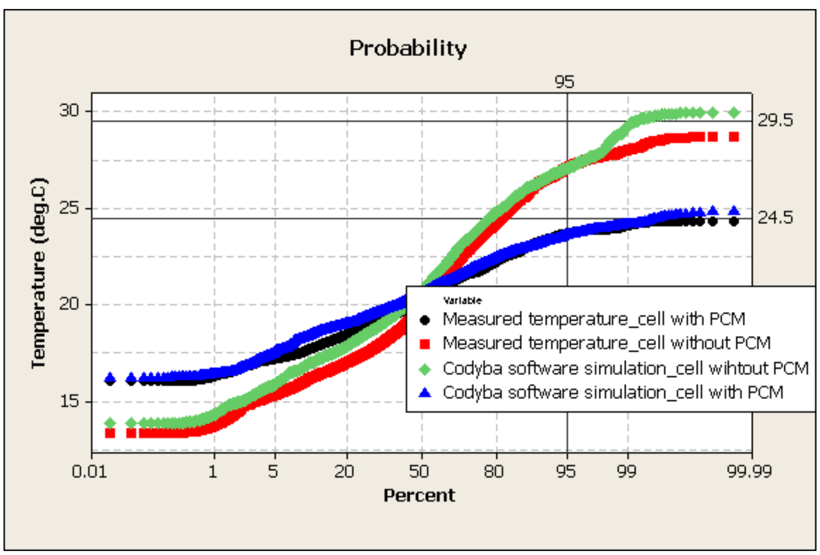
DuPont Building Innovations worked together with UK software supplier EDSL and French software company IZUBA Energies on the integration of PCM in dynamic thermal validation software to facilitate the simulation of Energain® benefits.

SOFTWARE	**For more information, please visit:**
EDSL Tas	http://www.edsl.net

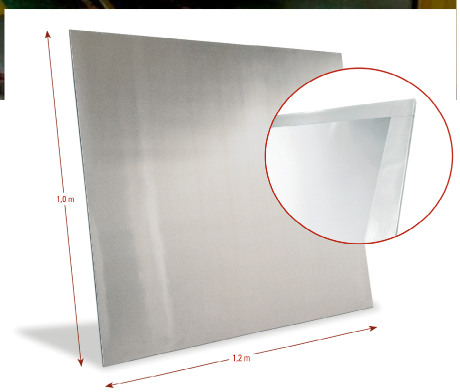
Both software modules enable the simulation of a specific building zone or entire building with and without Energain® providing a performance comparison for a selected period or entire year for geographic specific climate conditions.

Why put trust in the simulation?

DuPont has conducted a real life experiment with EDF France over a period of 8-9 months covering different seasons in a moderate climate zone (Paris region) to determine the Energain® product performance and prove the simulation software performance developed for the product specification.



As shown in **diagram 15**, the simulated temperature reach probability is very close to the actual measured temperature in the building.



DuPont™ Energain®

Authors:
Jacques Gilbert, DuPont de Nemours (Luxembourg) S.à r.l.
Ulrike Koster, DuPont de Nemours (Luxembourg) S.à r.l.

DuPont Building Innovations
DuPont de Nemours (Luxembourg) S.à r.l.
Rue Général Patton
L-2984 Luxembourg
E-mail: energain@lux.dupont.com
Website: http://www.energain.dupont.com