We've seen in the last couple of articles that high thermal mass reduces overheating in summertime and maximises solar gains in spring and autumn. For a contemporary new build, high thermal mass inside the insulation layer generally leads to lower fuel bills. (See the Footnote.)

So where does that leave a construction method like timber-frame, which essentially has low thermal mass?

**Phase Change Materials**

New types of board are becoming available in the UK for lining walls and ceilings. The boards incorporate Phase Change Material (PCM), which, in effect, adds a lot of thermal mass.

Examples of phase changing are the melting of ice into water (at 0°C) and its converse, the freezing of water into ice (generally at –2°C). A lot of energy is required to melt a solid into a liquid. (The energy involved in a phase change is called 'latent heat'.) The change of state of ice at 0°C is too cold to be of use in our context, but there are paraffin waxes which melt at more useful temperatures, eg, between 21°C and 26°C. And they have high latent heats. How can such a wax be utilised? Incorporating it into a wall board would be of no use if the wax simply melted onto the floor.

There are, in fact, two different technologies being used:

- **Dupont's Energain**
  This panel contains an ethylene based polymer (40%) that binds paraffin wax (60%). The 5mm thick panel is faced with aluminium. Size: 1 x 1.2 m. After being fixed, the panels need to be covered with plasterboard. The melt point is 22°C. And when the temperature of a panel falls below 18°C, its stored heat is released. (The melt point and freeze point differ.)
  Dupont claim that the heat storage capacity of the panels is 515 kJ/m². (1 kiloJoule = 0.28 Watt-hours.)
  Cost: about £40/m².

- **Knauf's Comfortboard**
  This plasterboard incorporates 'Micronal' PCM from the German company, BASF. The wax is contained in microscopic acrylic spheres. The transition (melting) temperature is 23°C, and the latent heat capacity is 200 kJ/m². This board is available taper-edged, 12.5mm thick, and 2m long. It can be worked as normal plasterboard, and finished with taped joints or skim plaster.
  Cost: about £70/m².

**Thermal mass equivalence between PCM boards and conventional materials**

According to Knauf, two layers of their Comfortboard have the same thermal capacity as a 10cm thick concrete wall. But the comparison is a simplification.

Let's consider a sunny morning in midsummer when the room temperature starts at 22°C.

Compare what happens with two types of construction:
• **Timber-frame wall lined with Comfortboard**

  As room temperature rises above 23°C, the wax in the Comfortboard starts to melt, thereby absorbing heat and maintaining the board temperature at 23°C. Which is excellent. But with prolonged sunshine, there may come a time when all the wax has melted. The board then behaves like ordinary plasterboard – its temperature is likely to rise rapidly if the sun continues to shine into the room. So it is desirable that Comfortboard is installed in a thickness that is sufficient to absorb all the heat that may come its way over the course of a sunny summer's day. A double layer is generally recommended by Knauf.

• **Cavity wall construction with plastered concrete blocks**

  As room temperature rises, heat is absorbed by the blocks and their temperature slowly rises. There is no steadying of the temperature at 23°C, as happened in the previous case. On the other hand, the blocks ability to absorb heat remains unchanged throughout the day. The blocks absorb heat as effectively at the end of a sunny day as at the beginning.

### Comparison of heat storage capacities

As mentioned above, the heat storage capacities due to phase change are 515 kJ/m² for Energain and 200 kJ/m² for Comfortboard. How do the heat storage capacities of these boards compare with the heat storage capacity of 10cm thick, aerated concrete blocks (Celcon, Thermalite, Durox, etc)? Here's a simplified comparison that ignores time delays in heat flows. (For the effects of 'Admittance', see September's article.)

The volumetric heat capacity of autoclaved aerated concrete: 600 kJ/m³°C. (Again, see September's article). So the heat capacity of a square metre of 10cm thick, aircrete blockwork is 60 kJ/°C (ignoring mortar joints).

As we have seen above, a square metre of Energain can absorb 515 kJ of heat at its transition. This amount of heat would raise the temperature of a square metre of the blockwork by 8.6°C. \((8.6 = 515 / 60.)\)

Likewise, the heat storage capacity of a square metre of Comfortboard equals the heat absorbed by a square metre of blockwork when its temperature is raised by 3.3°C. \((3.3 = 515 / 60.)\)

Concrete blocks are available in a wide variety of densities. Dense aggregate blocks have nearly double the heat capacity of the figure given above for aircrete blocks.

### Flammability

Paraffin waxes burn! And when they burn they give off smoke. So how well are these boards rated for fire resistance? – Not well.

The Energain board is rated as Class E under BS EN 13501: Reaction to Fire. (Class E is the worst class that passes the tests.) But note that Energain is usually covered with ordinary plasterboard.

Knauf's Declaration of Performance for Comfortboard shows that it is in Class D – better than Energain's Class E, but still well short of the Class A2 of Knauf's standard plasterboard.

### Hot pizzas
Readers may be amused to know one of the other uses of PCM's: keeping pizzas hot during delivery to a customer's home. The PCM used for this has a transition temperature of about 50°C.

**Future developments**

Though fairly new to the UK, PCM's have been used for many years in the USA, and they are widely used in homes there. (That may be in response to the greater use of timber framing in the USA and to its less temperate climates.)

Some common inorganic salts have suitable melting temperatures and high latent heats. Will we see these incorporated in the future into PCM boards? Such a board is likely to be less flammable.

PCM's are also available in the USA incorporated into insulation. This effectively increases the thermal mass of the insulation, which may be desirable in some situations. Will such insulation become available here, too? (Wood fibre insulation is available in the UK, eg, Pavatex, and one of the advantages being claimed for it is that it does have much higher thermal mass than mineral wool or plastic insulation.)

**DYNAMIC THERMAL PROPERTIES CALCULATOR**

This calculator, an Excel spreadsheet by Arup, can be downloaded for free from the website of the Concrete Centre. It is simple enough to use – all the sophisticated mathematics goes on behind the scenes. As downloaded, the spreadsheet initially shows a cavity wall as an example: dense plaster – dense blockwork – mineral wool insulation – cavity – brickwork.

For each layer of the construction, the thickness, density, specific heat and thermal conductivity are entered. (A sheet of reference data is included in the calculator for convenience.) Then simply click the 'Calculate' button, and lo – the Admittance, Decrement factor, Decrement delay, and κ-value are displayed. (See my last two articles for explanations of these terms.)
Technophiles who want to puzzle over the graphs should download the User Guide for the Calculator. Suffice to say:

The 'Internal environmental temperature' (ie, room temperature) is defined to be a sine wave, varying between plus and minus 1K (or 1°C in an alternative terminology). It continues before and after the 24-hour period shown.

At Hour 0, the room temperature is rising fast. The room temperature has become higher than the surface temperature, so the 'Internal surface heat flow' is positive, ie, heat is flowing into the wall (as shown in the graph). Likewise, the reader may be able to see how the direction and magnitude of the internal heat flow at other times are determined by the room temperatures in the recent past.

By the way, in real life the room temperature is unlikely to vary as an exact sine curve. But in 1822, a French mathematician, Fourier, showed how any cyclical variation can be considered to be made up of a number of sine curves with different periods (forming a 'Fourier series'). He did this to solve the heat equation, but the analysis has many other applications, eg, in acoustics, electrics, and the transmission of radio and mobile phone signals.

**Key results**

<table>
<thead>
<tr>
<th>Admittance [W/m²/K]</th>
<th>4.43</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrement factor [-]</td>
<td>0.25</td>
</tr>
<tr>
<td>Decrement delay [hours]</td>
<td>11.05</td>
</tr>
<tr>
<td>K value [kJ/m²K]</td>
<td>139</td>
</tr>
</tbody>
</table>

For further details see Full Results sheet.
The User Guide gives a useful definition of Thermal Admittance:

*The amount of energy leaving the internal surface of the element into the room per unit degree of temperature swing.*

( Presumably this is over one cycle, usually 24 hours. The amount of energy leaving must equal the amount entering the surface, as no energy is being transmitted through the element.) Because of the appreciable resistance to heat flow at the surface, there is, in practice, a maximum value for thermal admittance of about $8 \text{W/m}^2.\text{°C}$. Phase Change Materials are not catered for in the Calculator. For that, sophisticated software such as PCMexpress would be required – for professionals, not selfbuilders!

**A simple application of the calculator**

For this simple application let's consider a common question that arises in refurbishment: whether to add insulation on the outside or inside of a solid brick wall. As far as steady-state heat losses through the wall are concerned, the position of the insulation makes no difference. The total thermal resistance is simply the sum of the thermal resistances of the brickwork and the insulation. But does the order of the two layers affect the other thermal properties: decrement and admittance?

Let's enter the data for an imaginary wall of 20cm thick brickwork with 10 cm of mineral wool insulation into the calculator – firstly with the insulation on the inside, and then with it on the outside.

The Calculator gives the following results:

<table>
<thead>
<tr>
<th></th>
<th>Insulation inside</th>
<th>Insulation outside</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U value (W/m$^2$.°C)</strong></td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Admittance (W/m$^2$.°C)</strong></td>
<td>0.36</td>
<td>4.75</td>
</tr>
<tr>
<td><strong>Decrement factor</strong></td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>Decrement delay (hours)</strong></td>
<td>8.1</td>
<td>8.9</td>
</tr>
<tr>
<td><strong>κ-value (kJ/m$^2$.°C)</strong></td>
<td>0</td>
<td>175</td>
</tr>
</tbody>
</table>

**Thermal characteristics of a wall with insulation on the inside or outside**

The position of the layers makes no difference to the U values, a little difference to the Decrement factor and delay (affecting the passage of heat through the wall), and a lot of difference to the Admittance and κ-value (affecting the absorption, storage and release of heat at the wall's interior surface).

**Next month:** Passive Solar Design.

**FOOTNOTE:**

**SAP and heat savings**

According to Thermal Mass Explained, SAP calculations for masonry homes “show space heating savings of 15-30 per cent when compared to equivalent lightweight homes”. A sceptic might respond that Thermal Mass Explained is published by the Concrete Centre, and so is liable to be biased in favour of thermal mass. However, as we saw last month, according to the Minister of State for Energy and Climate Change,
SAP shows that higher thermal mass does generally result in a lower energy requirement for heating over the year.

FURTHER INFO

**Dupont Energain**
“As easy to install as standard plasterboards” – well, not quite as you have to seal cut edges with aluminium tape. And the panels need to be covered with plasterboard.
www.energain.co.uk.

**Knauf Comfortboard**
www.knauf.co.uk.

**Eco Building Boards**
Unfired clay board with 20% Micronal PCM. Storage capacity is 396 kJ/m2.
ecobuildingboards.weebly.com.

**Micronal PCM**
PCM powders manufactured by BASF with a choice of transition temperatures: 21°C, 23°C, or 26°C.
Look for the English link:
www.micronal.de.

**Dynamic Thermal Properties Calculator**
Arup's Excel calculator, with a User Guide.
Amongst other figures it calculates $\kappa$ (kappa value) for use in SAP.
Free download from:

**Thermal Mass Explained**
Published 2012 by the Concrete Centre. 12 pages.
Free pdf download from their website, as above.