Eco-Innovation Workshops -
Sustainable Building, Construction
and Energy Harvesting Technologies

Next generation materials and technologies

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Summary of talk

- Focus on reducing energy consumption
- Why are new materials and technologies needed – what are the drivers?
- What could these "*new*" materials, technologies and building designs be?
- What new measurement problems will these innovations pose – why will we need to measure / calculate their thermal properties accurately?
- The role of the NPL Thermal Performance Group in resolving new measurement and calculation problems.

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The drivers.

- **Combating climate change**
- **Ensuring Energy Security**
- The common denominator in tackling these issues has been identified by three government reports:
  - **USE LESS ENERGY**
- The following reports put “reducing energy consumption” as a vital first step in reducing man’s contribution to global warming and securing our energy supplies.
  - Royal Commission on Environmental pollution – Energy – the changing climate – 2000
  - White Paper “ Our Energy future – creating a low carbon economy” – 2003;
  - DTI Energy Review “Energy Challenge – 2006

Specific drivers for reduction in energy use

- Draft Climate Change Bill - intention of setting a legal framework for ensuring a (yet to be defined) specific reduction in $C0_2$ emissions by 2020 and a 60% reduction of 1990 levels by 2050.

- Code for Sustainable Homes published by the Department for Communities and Local Government in 2006 – with it's route to producing "zero carbon" homes by 2016 (a mere 9 years away)

DCLG – Code for Sustainable Homes

Achieving a sustainability rating

	Minimum Standards				
	Energy		Water		
Code Level	Standard (Percentage better than Part L[1] 2006)	Points Awarded	Standard (litres per person per day)	Points Awarded	Other Points[4] Required
1(★)	10	1.2	120	1.5	33.3
2(★★)	18	3.5	120	1.5	43.0
3(★★★)	25	5.8	105	4.5	46.7
4(★★★★)	44	9.4	105	4.5	54.1
5(★★★★★)	100[2]	16.4	80	7.5	60.1
6(★★★★★★)	A zero carbon home[3]	17.6	80	7.5	64.9

Reduction in the energy used in buildings is vital

- About 40% of national energy consumption is in buildings.
- About 30% of national energy consumption is in homes.
  - 60% heating
  - 20% hot water
  - 20% everything else
- More energy passes through glazing in buildings than is used by UK industry.
- The number of households is set to rise:-
  - 2002 59M people lived in 25.6M households
  - 2050 66.8M people will live in 31.8M households

Reduction in energy use in buildings is driven by regulations and needs to be enforced by ensuring strict adherence to measurement and calculation standards

- Energy is too cheap for the market to produce significant change.
- Thermal performance can not easily be inferred from observation.
- Selection of the “best” product for a specific application will always have to rely on having access to good performance data

What will building thermal performance regulations require in the future.

Source of fabric heat loss	Rate of heat loss (U-value $W/m^2.K$) 1997 - 2004	2005 - 2009	2010 - 2019	2020 - 2029	2030 - 2039	2040 - 2050
Walls	0.35	0.3	0.2	0.1	0.1	0.1
Roof	0.24	0.15	0.1	0.1	0.1	0.1
Floor	0.35	0.2	0.15	0.1	0.1	0.1
Glazing	2.2	2.0	1.5	0.8	0.8	0.8
Doors	2.5	2.0	2.0	2.0	2.0	2.0
Ventilation heat loss (air changes per hour)	2.0	1.5	0.6	0.6	0.6	0.6

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Important facts and assumptions needed to achieve 60% reduction

- UK has one of the oldest and least efficient housing stock in Europe.
- 21.8M pre 1996 homes still in use in 2050
- A total of 3.2M demolitions of the worst houses to be carried out before 2050
- Refurbishment assumed to have occurred:
  - 100% of windows (0.8 W/m2.K)
  - 15% of solid walls insulated
  - 100% of cavity walls insulated
  - 35% of cavity walls have additional external cladding
  - 100% roofs have 300 mm insulation

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Traditional INSULATION materials

- Basic principle - reduce convection and radiation by using a minimum of material to keep conduction through the solid to a minimum.
- Air based insulations (eg expanded polystyrene, glass fibre) limited to about 0.032 W/m.K (would need 320 mm of insulation in walls to attain 0.1 $W/m^2.K$)
- Gas blown insulations (eg polyurethane, polyisocyanurate) can get as low as 0.017 W/m.K (would need 170 mmm of insulation in walls to attain 0.1 $W/m^2.K$).
- Thermal resistance of air cavities can be increased by using low emissivity surfaces.
- Thermal resistance of air cavities can be increased by filling with gases such as Argon, Krypton, Xenon (lower thermal conductivity and they convect less readily).

EMERGING INSULATIONS (Dependent on vacuum)

- **Vacuum**
  - High vacuum (<10^{-6} Torr) has a very high thermal resistance – essentially just radiant heat transfer - zero convection. With two low emissivity surfaces a thermal resistance of about 6 m^2.K/W is achieved (equivalent to over 200 mm thickness of glass fibre). (NB: container walls can be a serious cold bridge problem)
  - Not practical in buildings (although evacuated glazing is a possibility)
- **Evacuated Aerogels and evacuated powder filled panels**
  - Use powder particles or closed cell aerogels with small particle sizes and small cell sizes respectively, in a vacuum tight container.
  - Require only a "modest" vacuum to increase the mean free path length of the gas molecules to about the same as the particle or pore diameter.
  - Even with poor vacuum, pressures of 50 Torr, very low thermal conductivity values of around 0.005 W/m.K can be obtained. (would need 50 mm of insulation to attain a wall with a U-value of 0.1 W/m^2.K).
  - This level of vacuum can be obtained and maintained relatively easily.
  - Still expensive and fragile (relative to traditional building materials).

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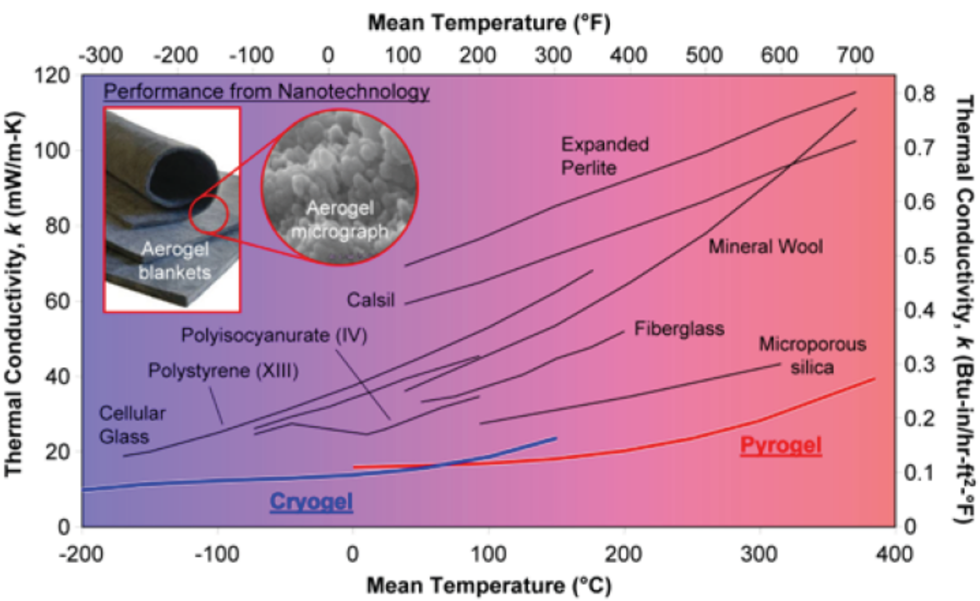
EMERGING INSULATIONS (Not dependent on vacuum)

Non-evacuated aerogels (eg product made by ASPEN)

- Aerogels are lightweight silica solids derived from a gel in which the liquid component has been replaced with gas. The silica solids, which are poor conductors, consist of very small, three-dimensional, intertwined clusters that comprise only 3% of the solids. Volume conduction through the solid is therefore very low. The remaining 97% of the volume is composed of air in extremely small nanopores which inhibits both convection and gas phase conduction
- The most important aspect of these materials is their flexibility and robustness



Emerging Insulation – (Gas filled)

Gas filled panels

- Gas-Filled Panels (GFP) are thermal insulating products that retain a high concentration of a low-conductivity gas, at atmospheric pressure, within a multilayer infrared reflective baffle. GFPs are flexible, self-supporting and can be made in a variety of shapes and sizes to thoroughly fill most types of cavities in building walls and roofs
  - Air filled - 0.028 W/m·K
  - Argon filled - 0.020 W/m·K
  - Krypton filled - 0.012 W/m·K

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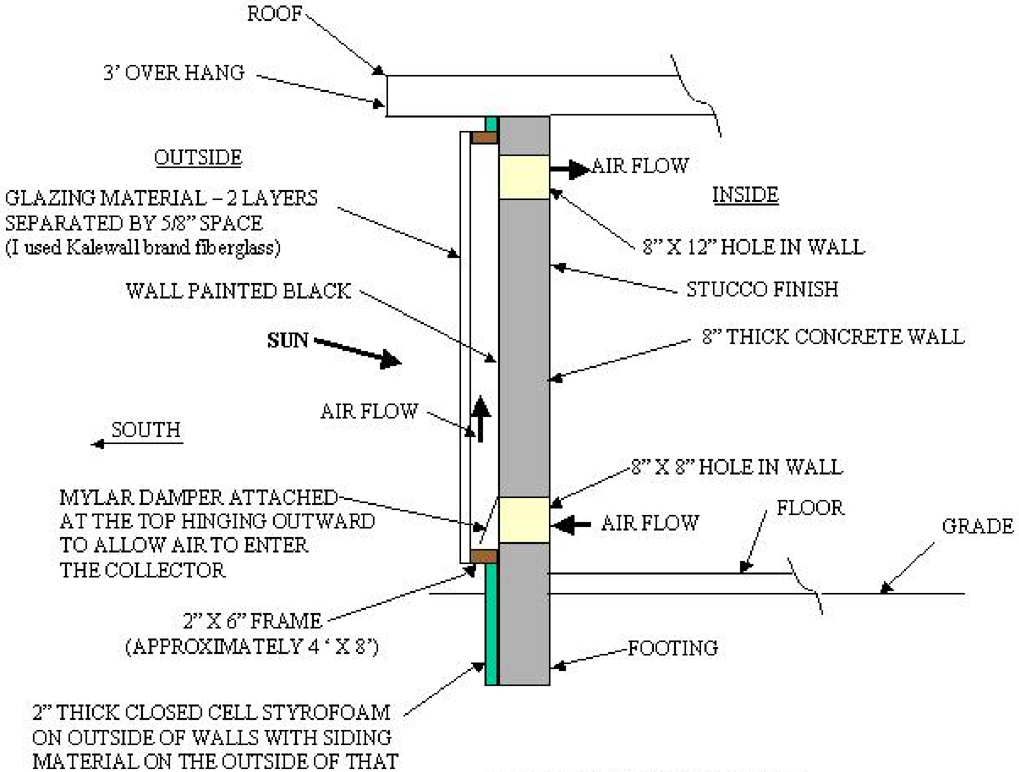
Efficient use of incident solar radiation

- Maximise solar gain when heating is required
- Minimise solar gain when it is not.
- Use solar energy to drive “natural” ventilation
- Good building design

  Eg - South facing atria with facilities to distribute warmed air throughout the house
- Trombe walls (glass panel in front of a masonry wall – explanation in next slide)
- Appropriate solar control systems
  - light shelves, external blinds, intelligent controls
  - Solar control coatings
  - SMART solar control coatings

Utilising Solar Energy - Trombe Wall



MODIFIED TROMBE WALL

New building designs and construction materials

- High thermal inertia buildings
- Phase change materials to store energy
- Industrialised building methods (better manufacturing tolerances)
- Low thermal conductivity composites for structural purposes and window frames (reducing cold bridging effects)
- Very air tight buildings with controlled air transfer – utilising heat from exhaust air and waste hot water to pre-warm incoming air.

New materials and technologies will need new measurement and evaluation methods.

- UK regulations and EU Directives are the main weapon in the armoury of European Governments in their fight to drastically reduce energy consumption.
- It is important to be able to accurately measure the thermal performance of all materials, products and designs used to reduce energy consumption in buildings because if the thermal performance of building materials & structures cannot be measured or calculated correctly – this vital, central plank of Government policy is seriously undermined.
  - To maximise returns on research and development by ensuring better performing products get an advantage in the market.
  - To ensure available resources are used to purchase the most appropriate products.
- An example of what can happen if we do not have standardised and accurate measurement methods established is how some reflective multifoil insulation materials have been marketed.

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Relective Multifoil Insulations

The reflective multifoil controversy

- Claims have been made that some reflective insulation systems - having an average thickness of 50 mm or less - have a thermal resistance of 5 m^2.K/W (equivalent to a traditional insulation 200 mm thick with a thermal conductivity of 0.04 W/m.K).
- These claims have been based on in-house comparative measurement methods.
- Millions of square meters of these materials have been installed on the basis of those claims.
- After some initial work was carried out by NPL, the Local Authority Building Control (LABC) issued an edict that the results of such tests should not be accepted until more was understood about these claims.
- NPL have just finished a research project
  - measuring the steady state U-values of roof structures (measured at different orientations) insulated with different products.
  - Measuring the dynamic thermal performance of both glass fibre and one of the multifoil products

Emerging Measurement Issues

We will need to:-

- Validate dynamic thermal performance values of structures
- Validate solar gain data being used to select products.
- Validate the thermal performance calculations and software in routine use.
- Be able to measure very low thermal transmittance of structures (<0.2 $W/m^2.K$) and high thermal resistance values of thin materials.
- Be able to carry out in-situ U-value measurements.
  - In controlled test cells to be able to evaluate the overall energy performance of products.
  - In actual buildings to evaluate effect of real installation issues
- Need to have validated life cycle analysis data.

These needs demand an infrastructure of thermal measurement capacity and understanding

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The facilities of the NPL Thermal Performance Group

- Established in the late 1970’s
- Wide range of facilities for measuring the thermal performance of materials and structures
  - Insulation materials (from –170 ºC to 100 ºC)
  - Masonry (-20 ºC to + 80 ºC)
  - Refractories (up to 850 ºC)
  - High temperature insulation (up to 850 ºC)
  - Plastics, Composites and ceramics (-50 ºC to +200 ºC)
  - Metals (up to 500 ºC)
  - Pipe insulation (up to 250 ºC)
  - Structures used in buildings (Masonry up to 450 kg / all orientations)
- Active members of CEN and ISO Expert working Groups writing measurement and calculation standards in this field

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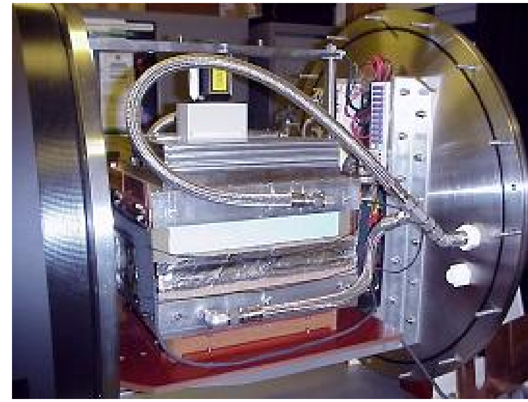
Thermal performance of homogeneous materials
- Thermal Conductivity (W/m.K) – UKAS facility -170 °C to 850 °C

0.3 m x 0.3 m &
06 m x 0.6 m GHP
–30 °C to +100°C –
Standard apparatus



Vacuum GHP –
unique in UK

Very low temp
GHP – Unique
in UK

50 mm

GHFM

850 °C GHP –
Unique in UK

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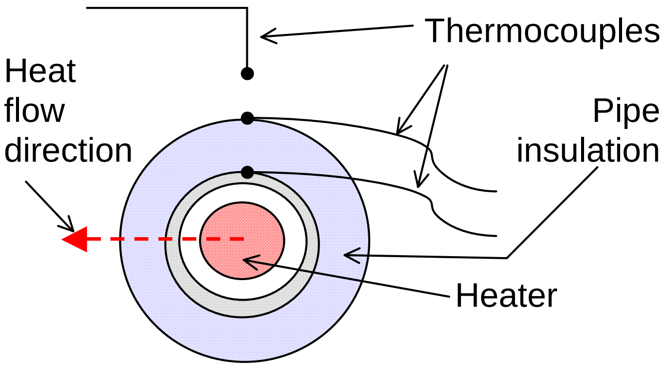
Thermal Transference of Pipe Insulation (BS EN 8497)

Thermal efficiency is also of importance in industrial processes



End heat flows corrected by using the Van Rinsum method

49 mm diameter pipe insulation thermal transference measurement apparatus

- the only such facility in the UK

Wall Guarded Hot Box Apparatus (UKAS)

Masonry conditioning chamber - RH from 5% to 95% @ 23 °C

or dried @ 110 °C

Wall Guarded Hot Box – U-values of structures

Rotatable Wall Guarded Hot Box (UKAS)

Tests can be carried out at all orientations

Rotatable Wall Guarded Hot Box

Some of the CEN & ISO Standards which this Group has contributed to

- **CEN TC 89 WG7** - **Curtain Wall – Calculation of U-values**
- **CEN TC 89 WG7** - **U-value measurements of windows & doors**
- **CEN TC 89 WG7** - **U-value measurements of roof windows**
- **CEN TC 89 WG7** - **U-value calculation (& FEA) of windows**
- **ISO TC163 WG14** - **Uncertainty analysis of hot box measurements.**
- **ISO TC163 WG11** - **Energy rating of window systems**
- **CEN TC89 WG11** - **Masonry λ measurement standard**
- **CEN TC89 WG11** - **High temp guarded hot plate standard**
- **SDG5 Expert Group** - **Key mark scheme for λ measurement insulations**
- **CEN TC 89 WG8** - **Guarded Hot Plate methods and apparatus**
- **CEN TC 89 WG8** - **Hot Box general methods and apparatus**
- **CEN TC89 WG12** - **Evaluating the thermal performance of reflective insulation**
- **BSI 540/B** - **UK mirror group (for UK industry) off international for thermal performance standards**

➢ **In progress now**

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Conclusions

- Energy conservation is a prime requirement for meeting the energy and climate change agenda.
- A range of innovative materials and building designs will be (are being) developed to meet these needs.
- New mandated requirements will require accurate and relevant measurement of new materials and products.
- There will be an increasing need to validate theoretical predictions.