Improving the Thermal Performance of Historic Buildings

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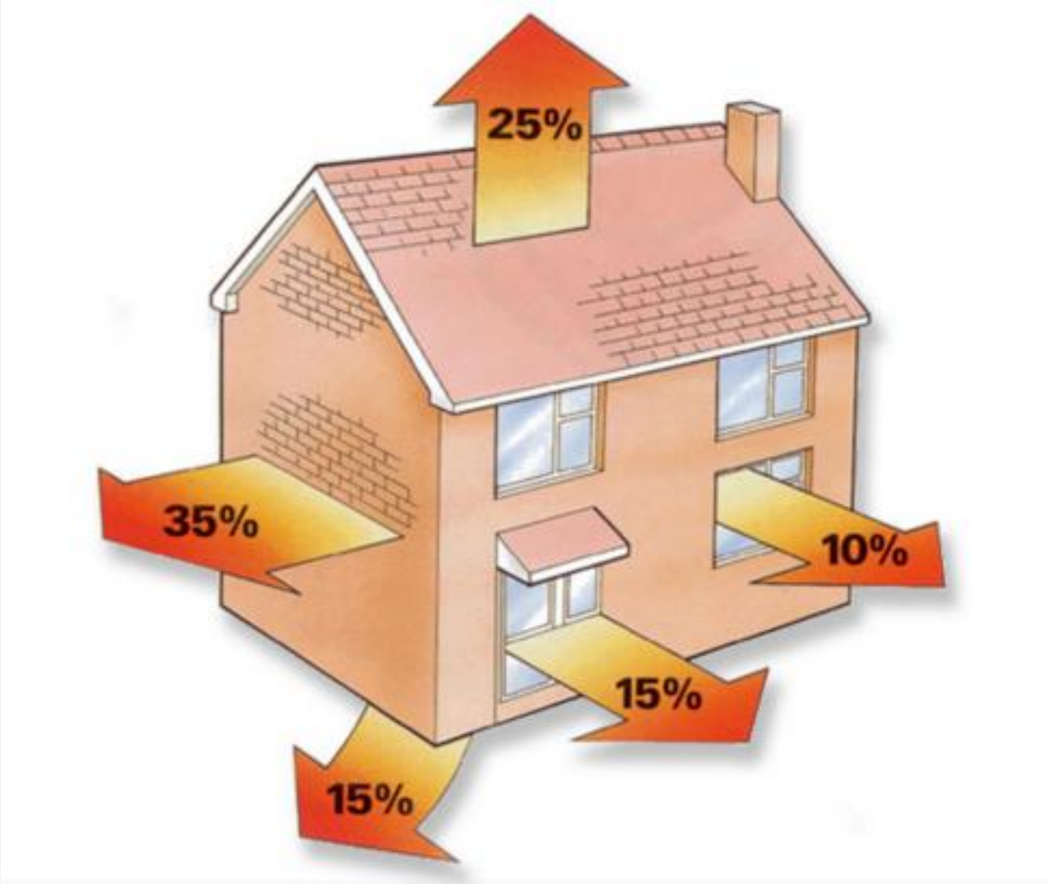
22nd October 2019

Research undertaken in Trinity College, Dublin
funded by OPW, IRC and SEAI

Heat Loss from a house



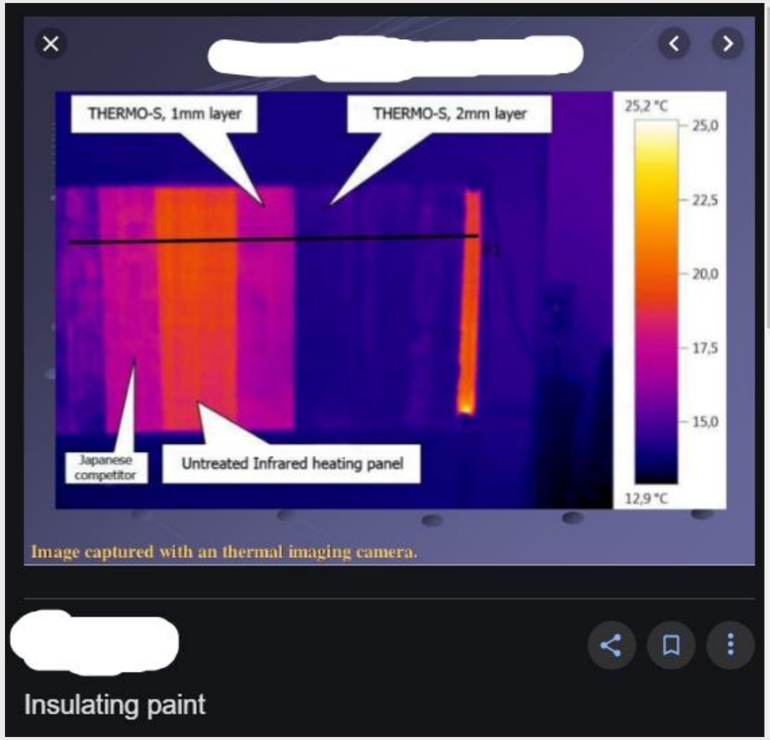
- Heat loss is building specific and <u>needs careful assessment</u>
- Depends on
  - Building typology (wall surface area), terraced, detached etc.
  - Building fabric/ construction technology cavity wall, single glazed windows
  - Age
  - Condition

Misleading information

“Old means cold…”

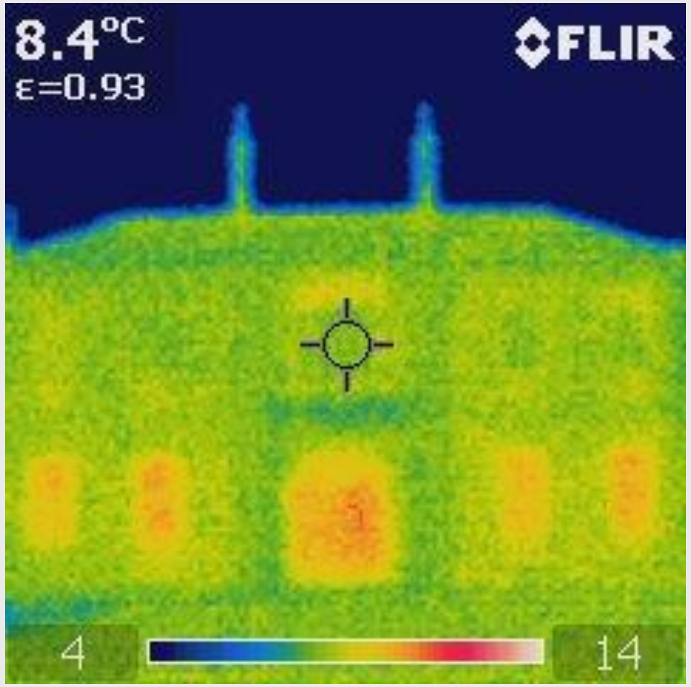
“Up to 35% less heat loss”

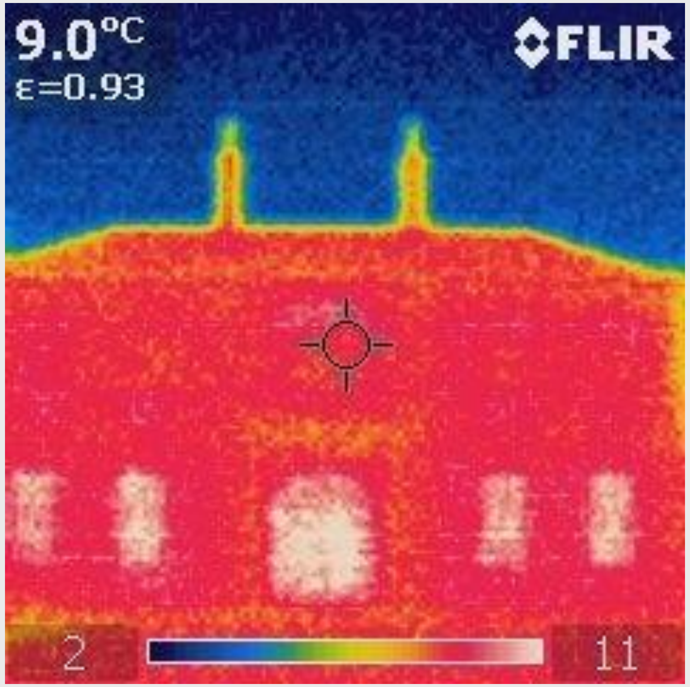
“It can be a real style choice to use old-fashioned décor like a thatched roof or big wooden door, But these images show that they’re not always the best in terms of insulation or keeping heat in”



Misleading information

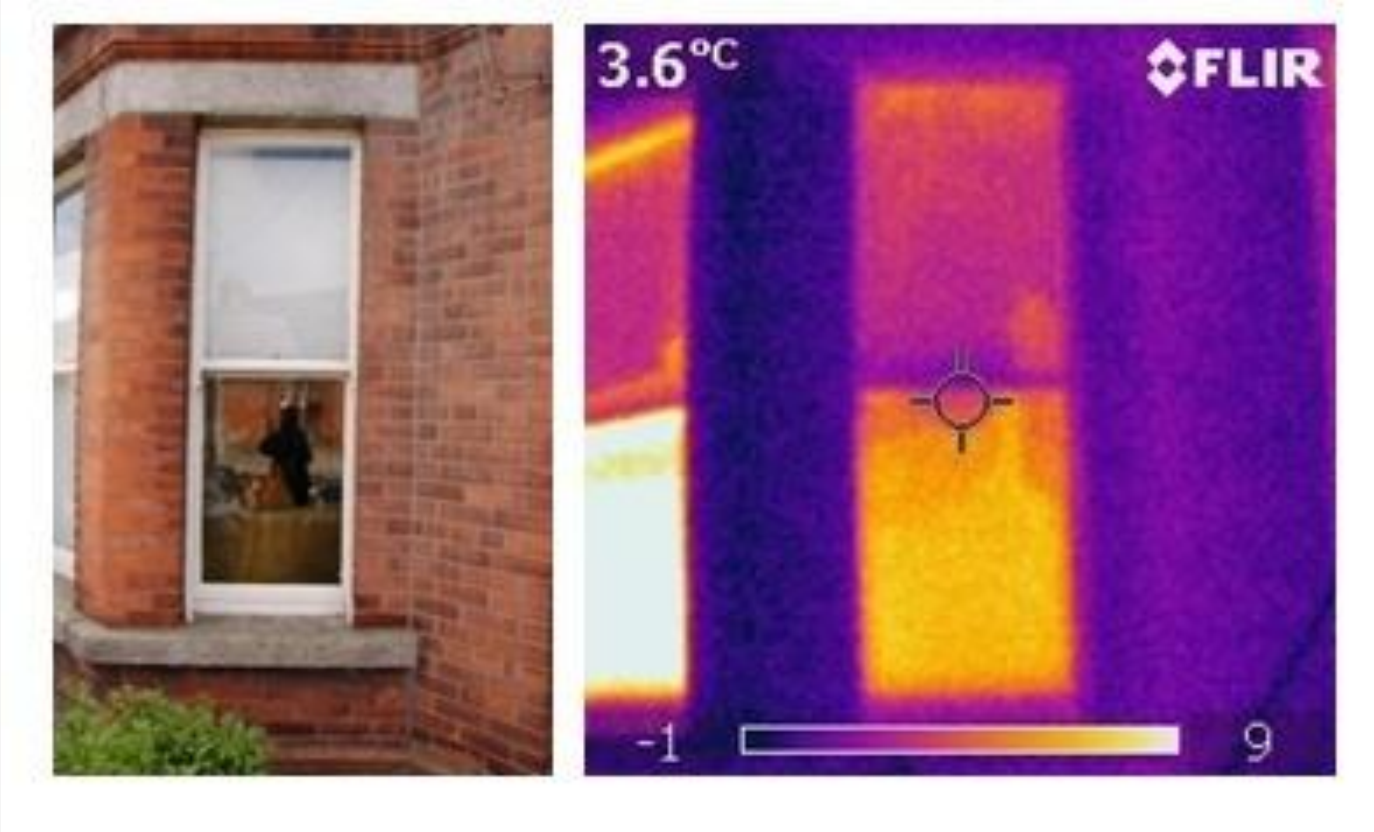
- Which building is loosing more heat?
- Is more heat being lost from the upstairs or downstairs?



Misleading information

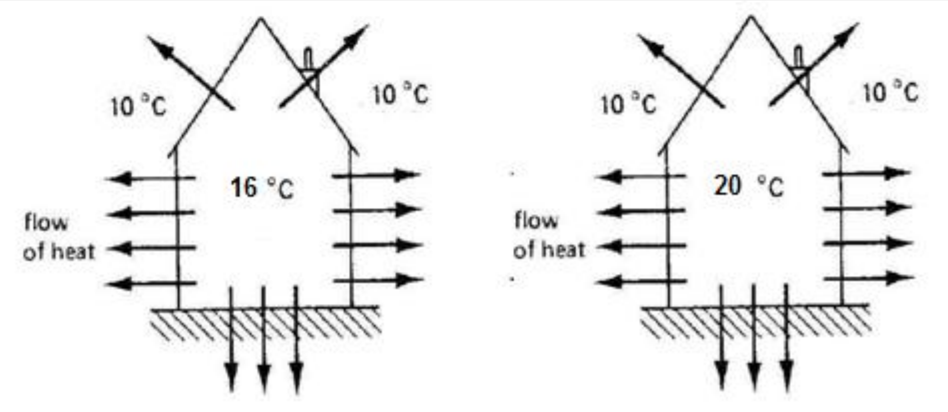
- Why are the exact same windows showing different amounts of heat loss?

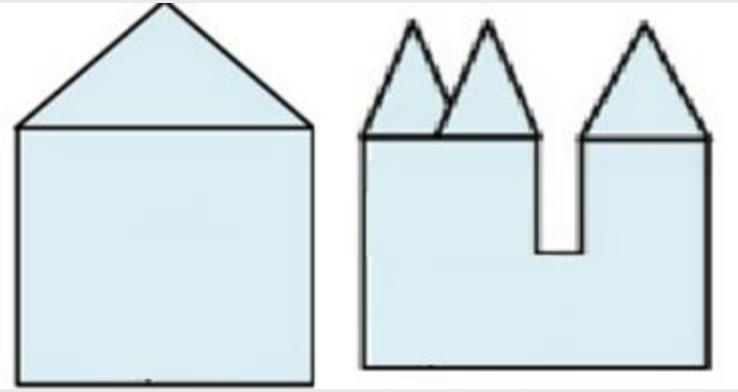


Simplified Heat Loss from a building (conductive)

- Heat loss = U x A x dT
  - U = U-value (Thermal transmittance) (W/m2K)
  - A = Area of surface (m2)
  - dT = Temperature difference

- To minimise heat loss reduce A, dT or U





Traditional vs modern construction

Traditional Walls

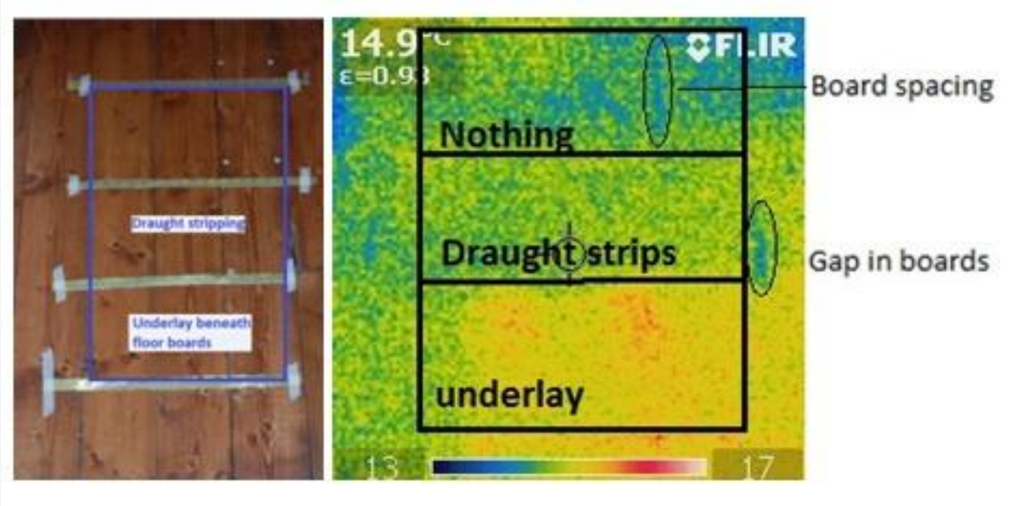
- Pre 1940
- Solid wall
- Natural materials ie brick, stone, cob/mud, lime
- Inhomogeneous and varying quality
- Allow movement – flexible building materials
- Permeable to moisture

Modern Walls

- Post 1940
- Cavity and solid wall
- Concrete, steel
- Homogeneous
- Strong, hard and rigid
- Resistant to moisture (cavities, dpm etc.)

Insulation for historic buildings

- Different construction approaches clearly have different insulation requirements
- Want insulating materials that are compatible with historic building materials
- Insulate
  - Roof – typically most cost effective and least invasive
  - Walls
  - Floor – insulate beneath floor
  - ~~Replace windows and doors~~



Suitability of internal wall insulation for historic buildings

- Alters the room proportions
- Interferes with the junction between the wall and plasterwork/joinery
- Thermal bridges are likely
- Not enough wall area – no point
- Increases the risk of moisture accumulation in the wall
- Planning permission for protected structures

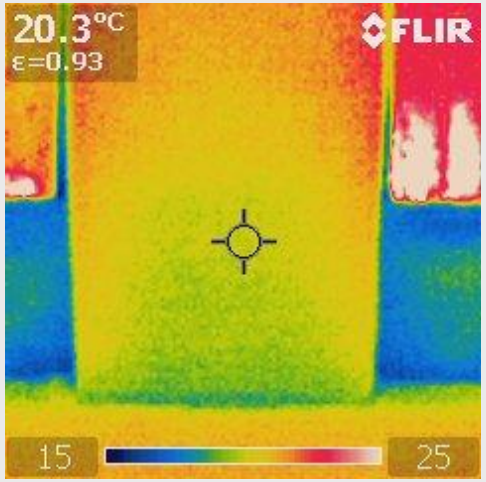
  - Is there a more appropriate alternative?

Alternatives to internal insulation

- Ensuring wall is in good condition
  - Repointing/rerendering
  - Repairing rainwater goods

  A wet wall is a cold wall
- Only insulating parts of walls such as recessed areas beneath windows where the wall depth is thinner and shutter boxes
- Thermal performance improvements in other parts of the building esp. roof
- Reasonable expectations

Image from www.volunteermold.com



Advantages of internal insulation

- Economic, environmental etc.
- Improve thermal comfort
- Can increase surface wall temperatures – thermal effusivity
- Can reduce air leakage through the wall
- External insulation is rarely an appropriate option

Selecting insulation

- Thermal properties
- Moisture properties
- Ecological properties
  - raw materials
  - embodied energy,
  - emissions (CO_2 etc)
  - indoor environment – off gassing of chemicals, mould etc.
  - Some insulations have the ability to act as carbon sinks ie hemp and wood fibre.

Selecting insulating materials

Calsitherm

Technical Details

Materials:	Calcium Silicate (sand and lime)
Thermal Conductivity:	0.059W/mk
Density:	180-187kg/m3
Compressive Strength:	>1 MPa
Water vapour transmission rate:	μ 3
Porosity:	90%

Thermoflex Wood Fibre Insulation

Technical Detail

Technical Data for chosen values

Joint Type	Blunt
Thickness (mm)	100
Length x width (mm)	1350 x 575 (UK)
Bulk density (kg/m3)	50
Nominal thermal conductivity λD(W/mK)	0.036
Thermal resistance RD (m2K/W)	2.60
Vapour diffusion factor (μ)	2
Sd-value (m)	0.20
Airflow resistivity (kPa·s/m3)	5
Specific heat capacity (J/kgK)	2100

Thermo- hemp

Technical Detail

Property	
Delivery form	batts
Thickness	40/50/60/80/100/140/200 mm
Length x width	580 x 1200/375 x 1200 mm
Bulk density	38 kg/m3
Components	82-85% hemp fibres, 10-15%
Thermal conductivity D(W/mK)	0.04
Water Vapour Diffusion Resistance Coefficient	1 - 2.

- https://www.ecologicalbuildingsystems.com/docs/Calsitherm%20Brochure%20120417.pdf
- https://www.ecologicalbuildingsystems.com/Ireland/Products/Product-Detail/Thermoflex-Wood-Fibre-Insulation
- https://www.ecologicalbuildingsystems.com/Ireland/Products/Product-Detail/Hemp-Insulation-Ireland

How does insulation lower the u-value of wall

- U Value of wall (1/ΣR)

$$\frac{1}{0.13 + 0.38 + 0.04} = 1.8 W/m^2 K$$

	Calsitherm	Thermoflex Wood fibre	Thermo hemp
Thermal conductivity	**0.059W/mk**	**0.036W/mk**	**0.04W/mk**
Calculating wall u-value with insulation	$\frac{1}{0.13 + 0.38 + 0.68 + 0.04}$	$\frac{1}{0.13 + 0.38 + 1.11 + 0.04}$	$\frac{1}{0.13 + 0.38 + 1 + 0.04}$
wall u-value with insulation	0.81W/m2K	0.6W/m2K	0.64W/m2K
% u-value improvement	55%	67%	64%

- Brick - λ=0.65 W/mK; d=0.25m; R = 0.25/0.65 = 0.38 m2K/W
- Ri =0.13 and Ro =0.04 m^2 K/W
- Insulation - λ=see table; d=0.04m; R = 0.04/ λ

Thermal properties for a range of insulation materials

TABLE III

THERMAL PROPERTIES OF INSULATION MATERIALS

material	Thick-ness	density	thermal conductivity	specific heat capacity	thermal mass	diffusivity	effusivity
		P	Λ	C_P	C_P P	Λ/(C_P P)	√ Λ C_P P
	mm	Kg/m^3	W/mk	J/Kgk	Kj/K m^2	m^2/S (X10¯8)	$J/m^2ks^{1/2}$
LP	40	1820	0.800*	863.90	62.89	50.88	1121.53
P	40	1820	0	866.80	63.10		
AG	19.5	509.4	0.016	1233.50	12.25	2.61	101.54
CL	40	806.2	0.065	866.50	27.94	9.26	212.54
HL	40	602.6	0.090	1068.00	25.74	14.06	241.33
CSB	35	402.0	0.089	819.40	11.53	27.08	171.39
TB	45	231.3	0.050	1217.80	12.68	17.61	118.23
PIR	37.5	233.4	0.034	1421.10	12.44	10.33	106.59

LP – lime plaster, P – thermal paint, AG – aerogel, CL – cork lime, HL - hemp lime, CSB – calcium silicate board, TB – timber fibre board, PIR

From: R Walker S Pavía, Thermal and hygric properties of insulation materials suitable for historic fabrics., COINVEDI III International Congress on Construction and Building Research, Universidad Politécnica de Madrid, December 2015, Escuela Técnica Superior de Edificación, 2015

Thermal performance of internal insulations

Project - Adjudant General's Building at RHK

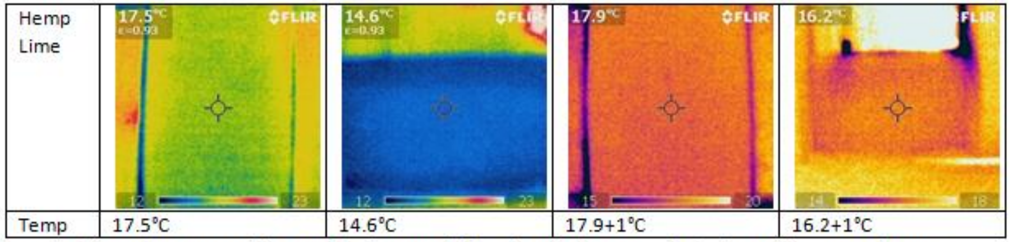


Fig 9. Thermal imaging of the wall before and after the application of the hemp-lime insulation.

		Thickness (approximate)	U- value	% U-value improvement compared to control lime plaster only
LP	Lime plaster	15mm	1.321	
P	Thermal paint on lime plaster	-	1.349	-2.12
AG	Aerogel with plasterboard	22.5mm	0.514	61.09
CL	Cork lime	40mm	0.727	44.97
HL	Hemp Lime	40mm	0.834	36.87
CSB	Calcium Silicate Board	36mm	0.870	34.14
TB	Timber board	47mm	0.601	54.50
PIR	PIR	40mm	0.540	59.12

Selecting insulation

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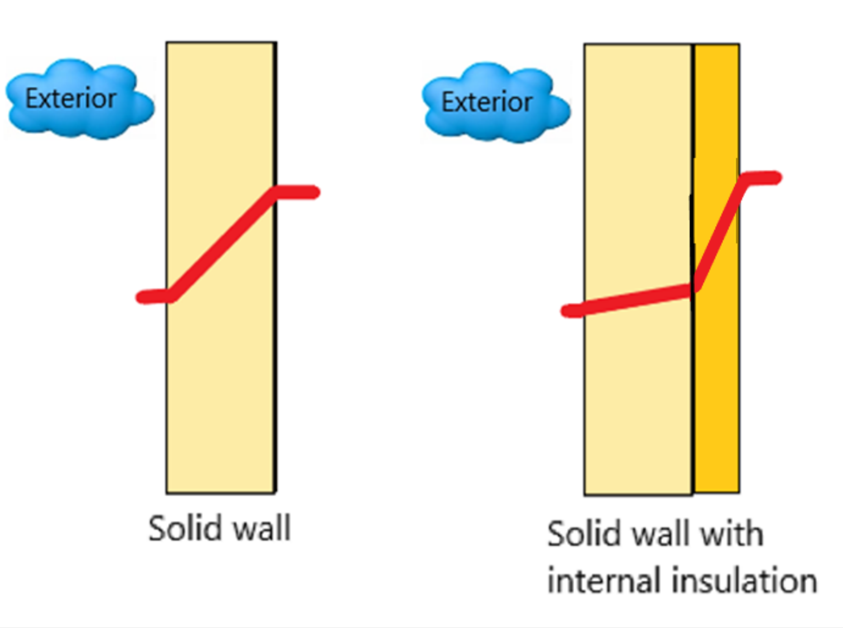
- Moisture properties
- Ecological properties
  - raw materials
  - embodied energy,
  - emissions (CO_2 etc)
  - indoor environment – off gassing of chemicals, mould etc.
  - Some insulations have the ability to act as carbon sinks ie hemp and wood fibre.

Moisture transfer with insulation

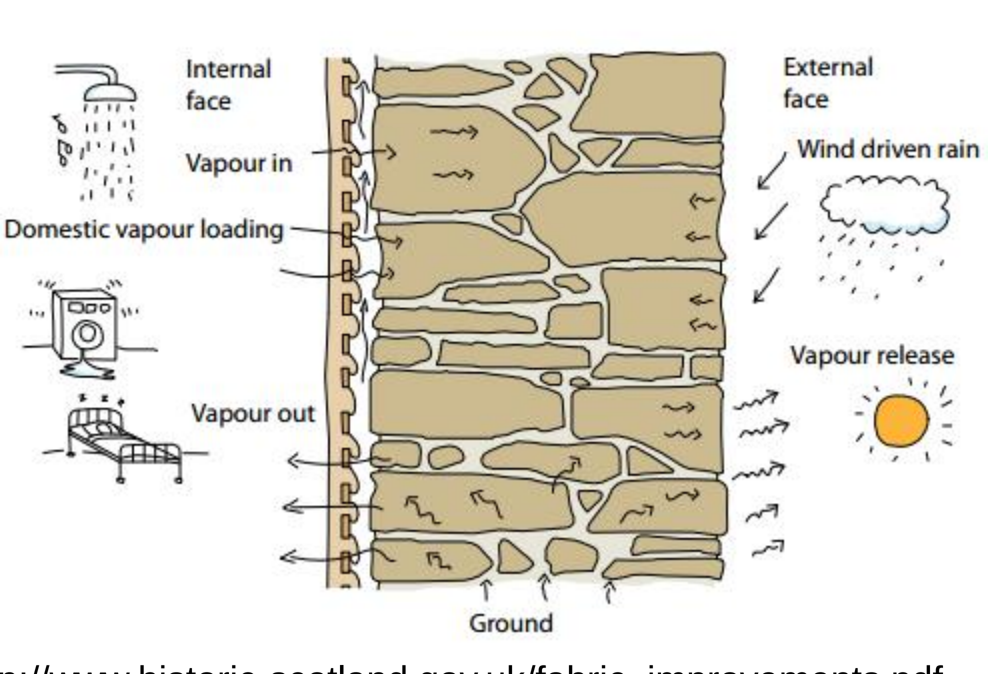
- knowledge gaps on the hygrothermal performance of insulated walls
- Internal insulation increases the risk of moisture accumulation in the wall occurs on account of the two primary reasons
  - insulation lowers the temperature of the wall resulting in reduced drying capacity of the wall and increased likelihood of moisture condensing within the wall.
  - reduced permeability of an insulation impedes the drying potential in the direction of the interior



Temperature gradient through a solid wall without and with internal insulation

Moisture properties

- Want internal insulation to be “breathable –
- Breathable describes “the extent to which building materials are able to transmit moisture” SPAB
- Want to ensure that moisture does not accumulate over time
  - the building materials can release moisture to the environment at a faster rate than it is input (by rain, humidity, leaks etc.)
- Moisture flow
  - Bulk water movement (liquid flow - rain, groundwater, leaks)
  - Capillary conduction
  - Air transported moisture
  - Vapor diffusion



http://www.historic-scotland.gov.uk/fabric_improvements.pdf

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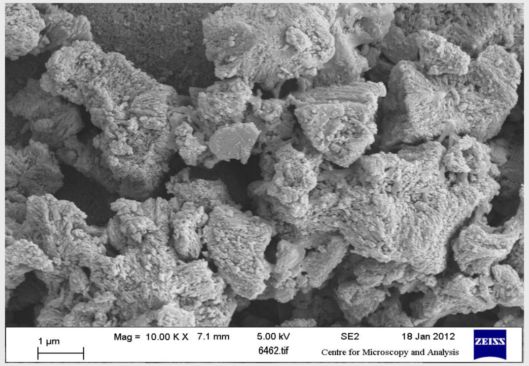
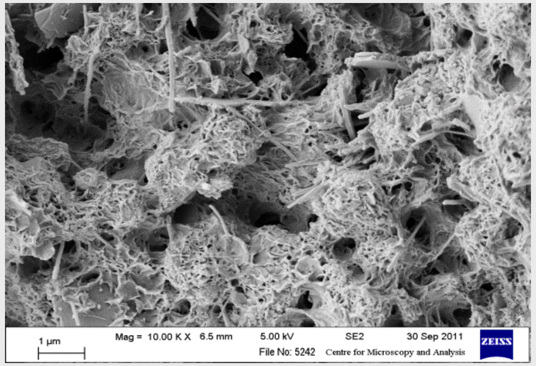
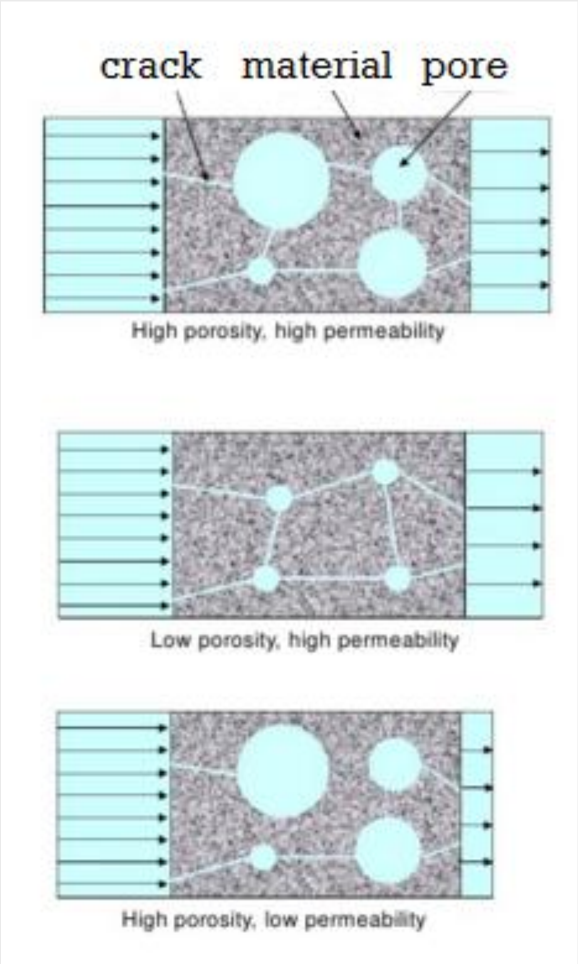
- https://www.ecologicalbuildingsystems.com/Ireland/Products/Product-Detail/Hemp-Insulation-Ireland

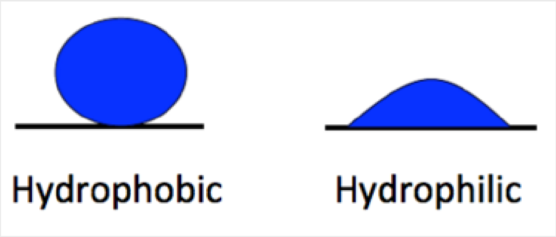
Moisture Transfer

- Moisture transfer is influenced by the characteristics of the building material
- pore structure
    - Quantity
    - Size
    - Connectivity
- hydrophillicity/hydrophobicity - degree a material surface attracts or repels water molecules respectively









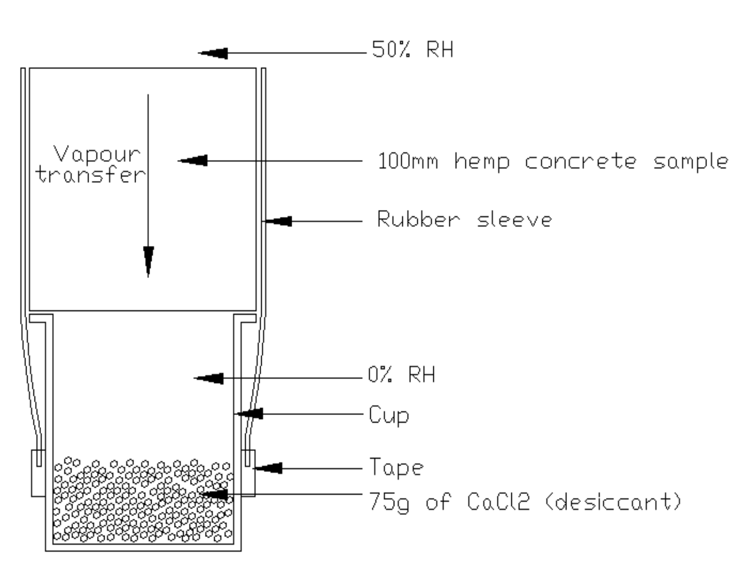
Moisture transfer

- Water vapour diffusion resistance factor (μ)
  - ratio of the resistance to moisture movement of a material compared to resistance of moisture movement to air)
- Vapour resistance (MNs/g) / Vapour Permeability (g/MNs)

$$\mu = \frac{\delta air}{\delta}$$

μ	water vapour diffusion resistance factor
δ_{air}	water vapour permeability of air
δ	water vapour permeability of the material

0.2 g.m/MN.s (this is a typical value in the UK for the vapour permeability of still air)



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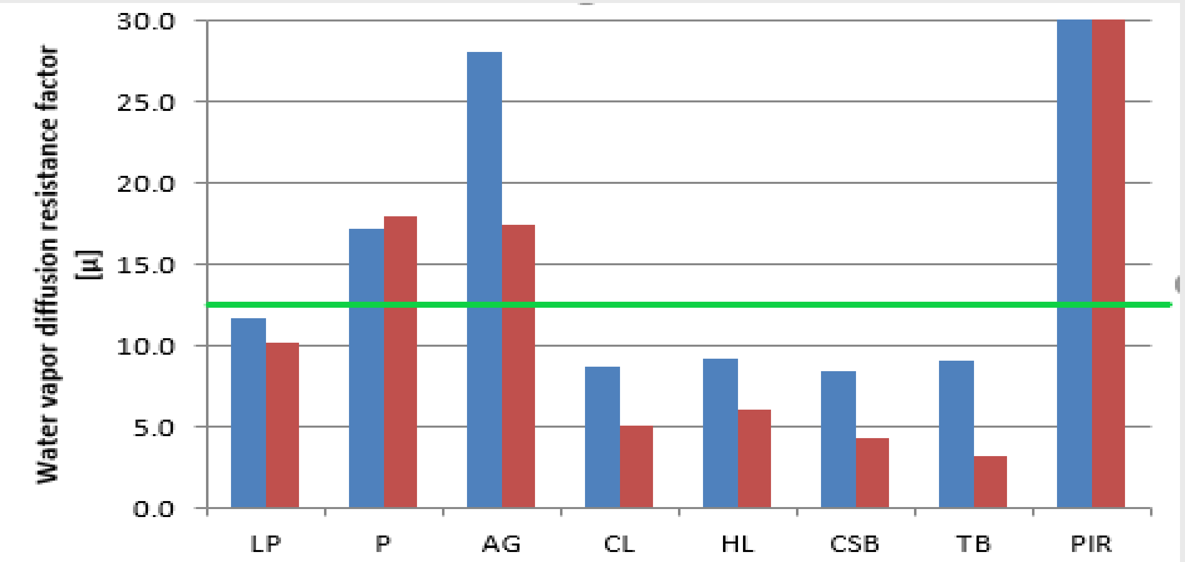
As a rough guide 'breathable' materials that could be considered suitable for use in older buildings should have a vapour resistance of below 2.5 MNs/g. (https://www.spab.org.uk/advice/breathability-and-old-buildings)

Water vapour diffusion resistance factor

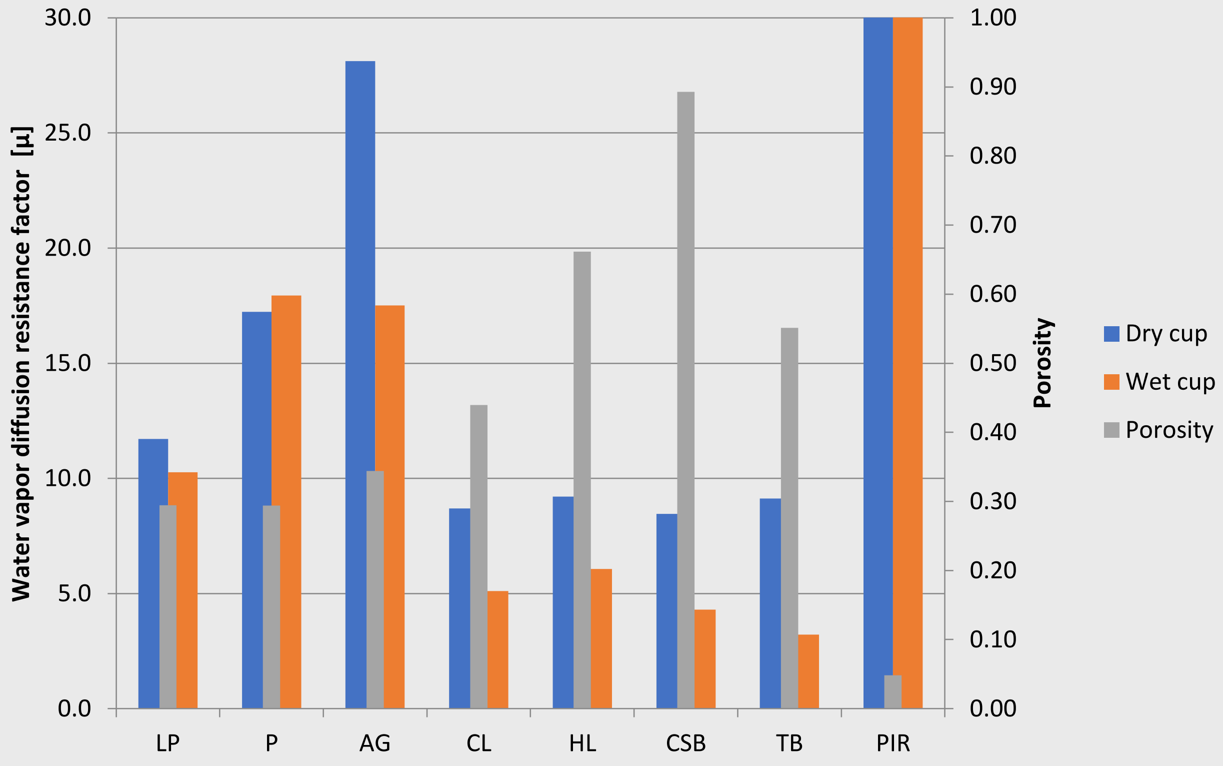
- Laboratory testing – Wet (NaCl) and dry (desiccant) cup

Material	μ - Dry Cup	μ - Wet cup
Lime Plaster	11.7	10.3
Paint	17.2	17.9
Aerogel with foil	28.1	17.5
Cork-lime	8.7	5.1
Hemp-lime	9.2	6.1
Calcium silicate board	8.5	4.3 **3 according to product tech details
Timber board	9.1	3.2
PIR	75.9	87.8



Wet cup (red) NaCl / Dry cup (blue) desiccant
Increase in vapor permeability during a wet-cup test may be partly due to liquid transport phenomena, and partly to shorter diffusion paths among water islands in the porous system formed by capillary condensation giving the indication of increased vapour permeability

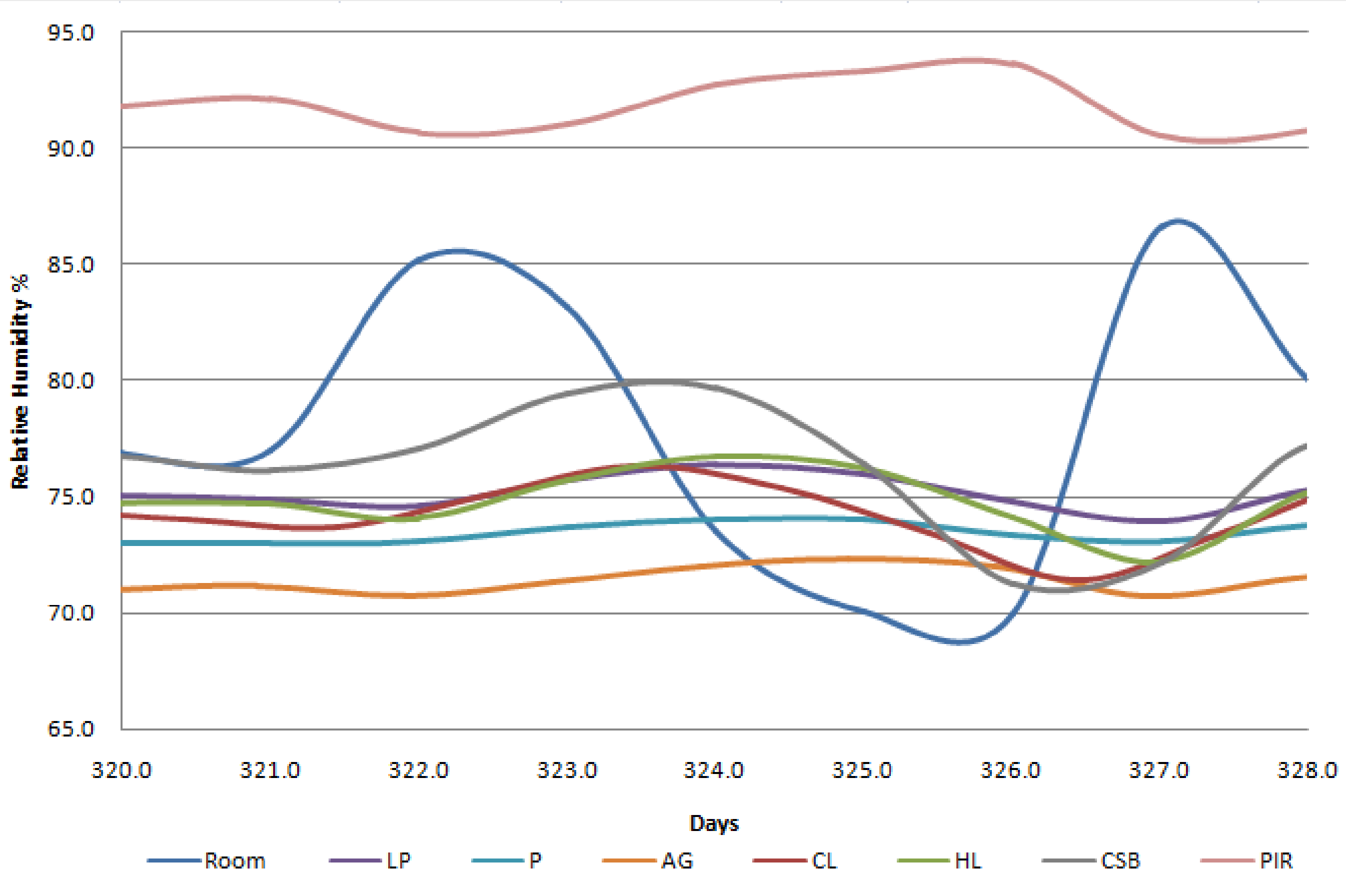
Water vapour diffusion resistance factor



Clear relationship where insulations with a high porosity have a high vapour permeability and vice versa.

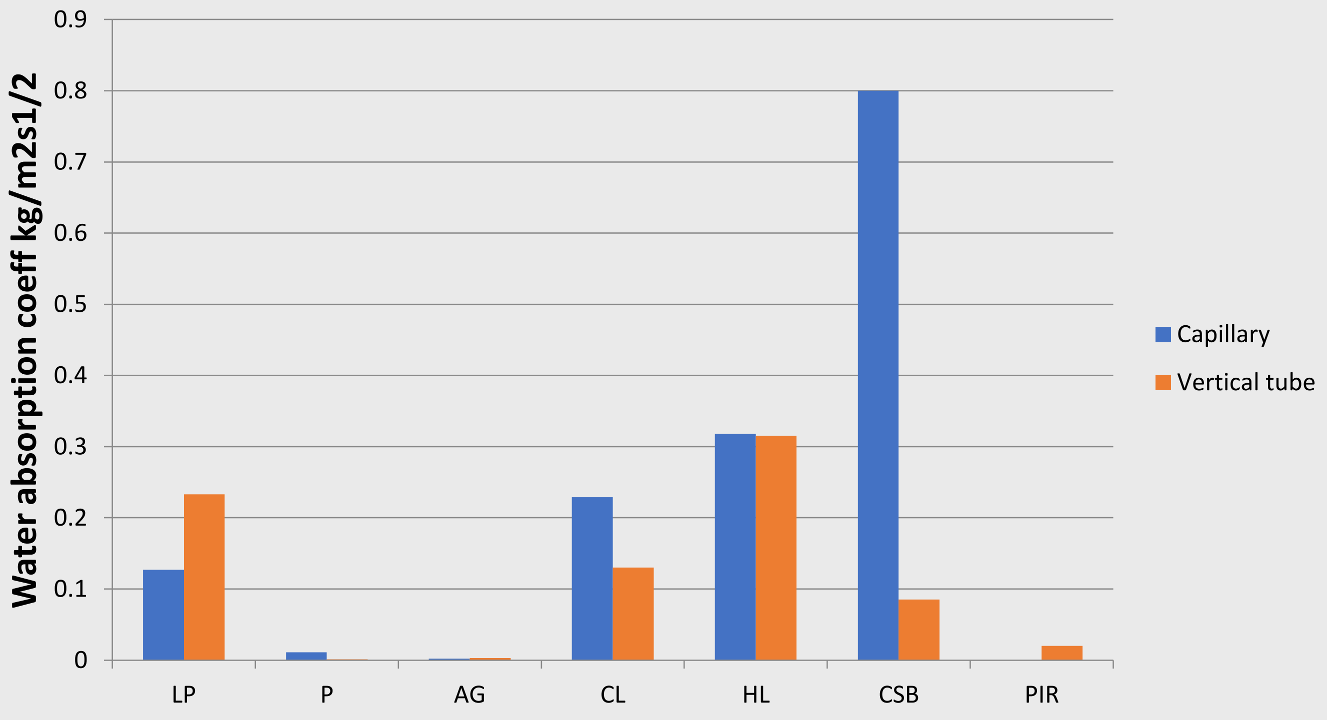
RHK Case Study - Fluctuations in internal wall RH

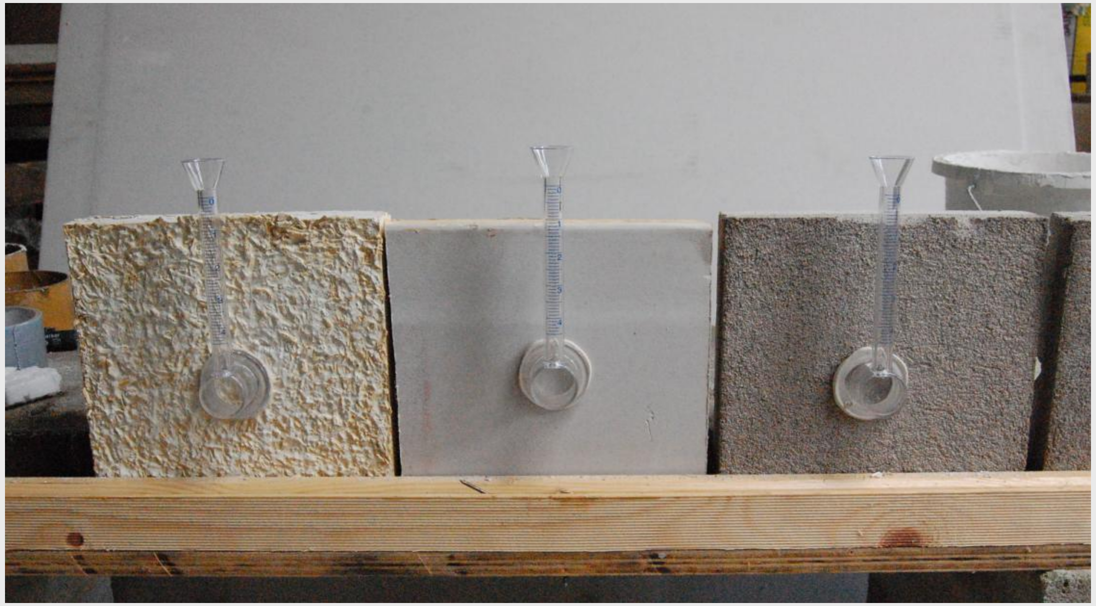
- The most vapour permeable insulations CSB, CL and HL have the greatest average internal fluctuations and also show the shortest delay
- the low vapour permeable P/AG display lower fluctuations in internal RH and longer lag periods



Moisture movement as a liquid

- Moisture can also move as liquid





Air leakage / Draughts

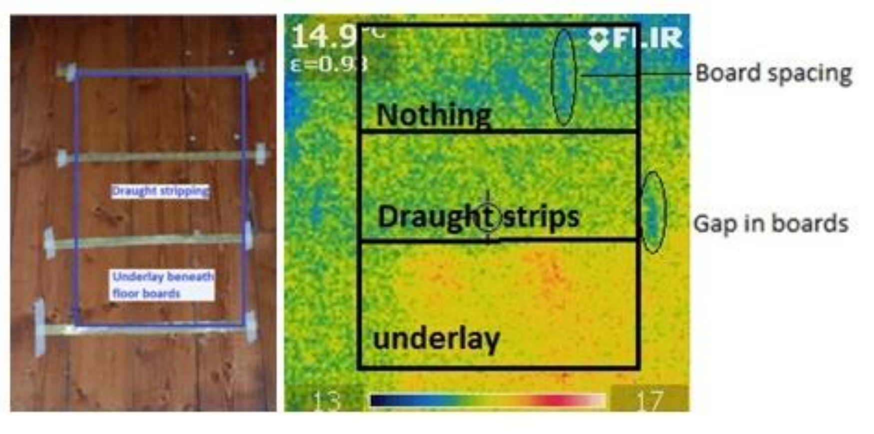
- Draughts are air currents caused by air movement into and out of a building - warm internal air is displaced by cool external air lowering room temperatures.
- There are no fixed proportions of air leakage that can be attributed to different building components such as walls, floors or roofs on account of the variety of building types, ages, building components and finishes that produce varying results in different buildings
- The DoEHLG (2011) estimates that easily avoidable air leakage is responsible for 5-10% of heat loss
- adequate levels of ventilation should be maintained to ensure the wellbeing of the building and its occupants.
- draughts have the equivalent effect of having a large window open all the time.

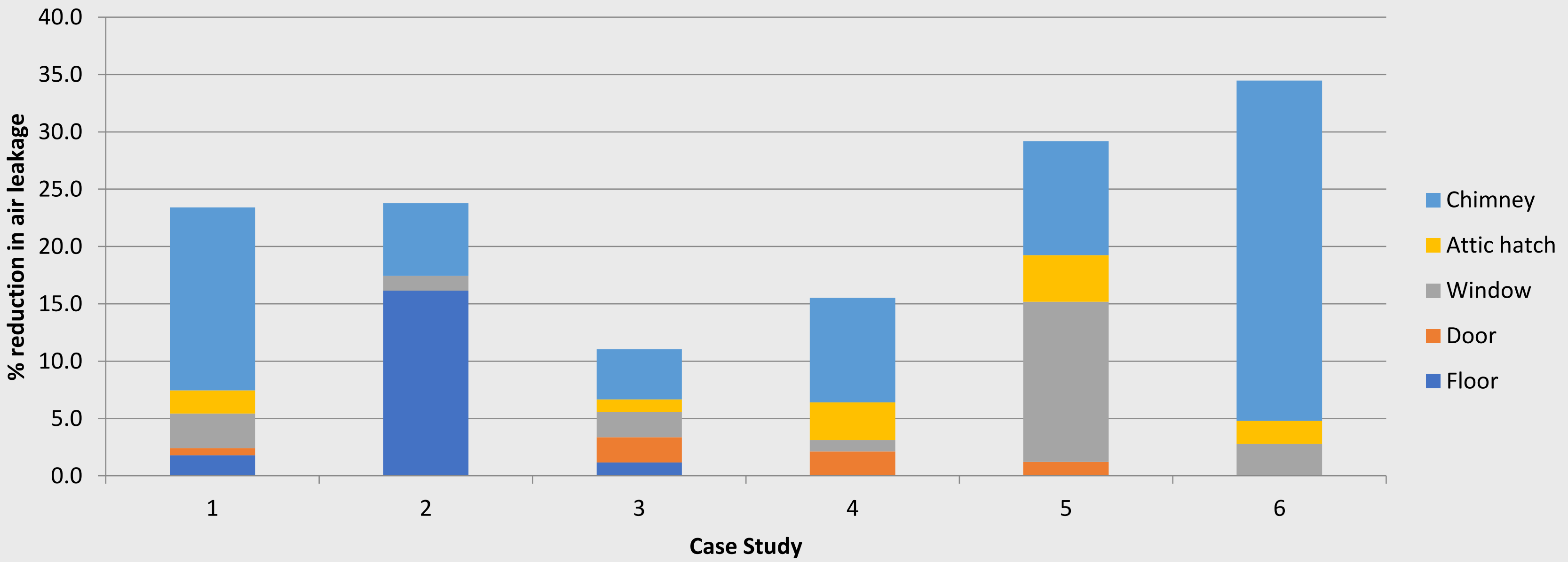
Project – Effectiveness of draught reduction measures

- 3 Victorian house and 3 mid 20th century houses

Overall findings

- Combination of draught reduction measures can minimise air leakage from houses by 10-35%.
- chimney balloons - 3-15% per chimney.
- Stripping the windows and doors - typically 1-2%.
- Stripping attic hatches - 0.3-3% per hatch.
- suspended timber floors - up to 16%





Thank You

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