Insulation

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Breathability - A White Paper

A STUDY INTO THE IMPACT OF BREATHABILITY ON CONDENSATION, MOULD GROWTH, DUST MITE POPULATIONS AND HEALTH

Kingspan®

Low Energy - Low Carbon Buildings

Contents

1 Executive Summary

1.1 If air-borne moisture is allowed to build up within a building it may lead to surface condensation, mould growth and exacerbated dust mite populations, which may in turn lead to an increase in health problems.

1.2 Air-borne moisture is transported in and out of buildings by two mechanisms, water vapour diffusion through the roofs, walls and floors of a building (breathability) and bulk air-exchange (intended ventilation plus air-leakage) in and out of the building.

1.3 Assuming a bulk air-exchange rate of 0.5 air changes an hour (the minimum considered to be healthy), ventilation accounts for 95% of the vapour transfer from a house with breathable walls.

1.4 If the bulk air-exchange rate is increased to a level that maintains the internal relative humidity at 65% (the ideal level to control mould and dust mites), bulk air-exchange accounts for 96.7% of the vapour transfer from a house with breathable walls.

1.5 Vapour diffusion (breathability) does not make a significant contribution to the rate of vapour transfer from a house.

1.6 **Breathable constructions and the breathability of insulation products** are therefore at best a side show, in reality they are **a complete red herring** in the avoidance of surface condensation, mould growth and exacerbated dust mite populations.

1.7 **Bulk air-exchange** (intended ventilation plus air-leakage) **is at least 19 times more important than breathability** in controlling air-borne moisture, surface condensation, mould growth, dust mites and consequent health problems.

2 Introduction

2.1 In recent times, many claims have been made about the benefits of breathable constructions in general and in particular of breathable insulation.

2.2 The basic argument that is ventured is that if constructions do not breathe then moisture will become trapped within a construction or within a building.

2.3 This moisture may lead to surface condensation, mould growth and exacerbated dust mite populations, which may in turn lead to an increase in asthma.

2.4 It has been argued that breathability has not been given much consideration because of the poor breathability of widely used synthetic building materials.

2.5 In order to verify these claims, Kingspan Insulation Ltd. commissioned Cambridge Architectural Research Ltd. (CAR) to carry out a study of moisture transfer and the significance of breathability in buildings*. The results of this study are summarised in this White Paper.

**A copy of the Cambridge Architectural Research report is available upon request from the Kingspan Insulation Marketing Department on 0870 733 8333 or literature.uk@insulation.kingspan.com.*

Dust mites thrive in environments with high relative humidity and their faeces is a human allergen.

3 Basic Principles and Consequences of Humidity

3.1 Absolute humidity is the quantity of water in a particular volume of air. The most common units are grams per cubic meter. Warm air can carry a larger quantity of water in vapour form without condensation occurring than can cold air.

3.2 The relative humidity (RH) of an air-water vapour mixture is defined as the ratio of the vapour pressure of water vapour in the mixture to the saturated vapour pressure of water at the prevalent temperature. Relative humidity is normally expressed as a percentage.

3.3 Water vapour pressure is the pressure of water vapour in Pascals (Pa) in equilibrium with liquid water. Water has a tendency to evaporate and condense. At any given temperature, there is a pressure at which water vapour is in dynamic equilibrium with its liquid water. This is the water vapour pressure at that temperature.

3.4 The saturated vapour pressure of water is the maximum vapour pressure of water than a body of air can hold at the prevalent temperature.

3.5 Condensation commonly occurs when the water vapour pressure reaches the saturation vapour pressure of water i.e. when the relative humidity reaches 100%. This usually occurs when a body of air containing water vapour is cooled and the saturation vapour pressure of water falls.

3.6 Ambient conditions frequently occur in which absolute humidity is high. Such conditions occur even more frequently within the home, where air is heated for much of the year above ambient levels and further sources of water vapour – human respiration, cooking, bathing and laundry – raise levels higher.

3.7 Building designers aim to avoid this air being cooled and thus avoid condensation formation.

3.8 It is known that damp conditions promote the growth of moulds and the population level of house dust mites, associated with higher incidence of asthma and allergic conditions.

3.9 Under laboratory conditions, moulds have been found to grow when RH reaches levels of 80% or above (70%) for some species. Nevertheless, a recent survey found significant levels of mould growth in rooms with RH levels of around 45%. The study attributed this to the fluctuating humidity conditions of most homes – levels rise for example when occupants take a shower or dry clothes indoors. It also found that much higher levels of RH occurred locally in areas of poor ventilation (for example behind furniture) or on cool surfaces.

Reduced ventilation in this case caused by blocked eaves ventilation gaps can give rise to condensation and mould growth.

A local drop in surface temperature can give rise to mould growth.

4 CAR's Calculation Results

4.1 Water vapour is transported in and out of buildings by two mechanisms, water vapour diffusion through the roofs, walls and floors of a building and bulk air-exchange (intended ventilation plus air-leakage) in and out of the building.

4.2 Since vapour pressure is normally higher on the interior of a building, water vapour tends to pass into building elements from the inner surface by diffusion.
This diffusion can be calculated under a range of conditions by using data on the thermal performance and vapour diffusivity (the water vapour permeability) of the materials concerned.

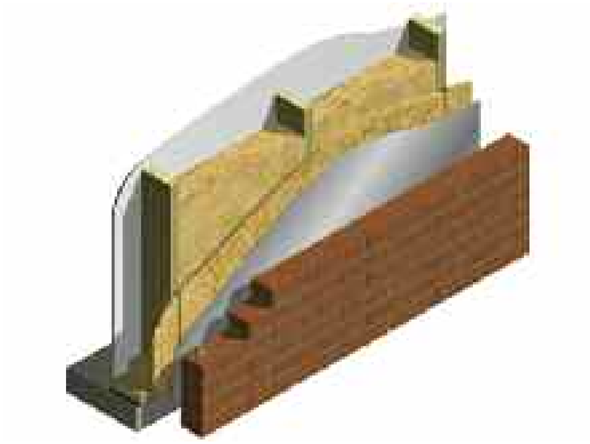
4.3 Given the specific moisture content for internal and external air, the net loss or gain of water vapour from or to the dwelling can be calculated for a fixed bulk air-exchange rate.

4.5 Below are the summary results of Cambridge Architectural Research's calculations exploring moisture transport by diffusion and bulk air-exchange. Details are shown in Appendix 1. For typical summer conditions, there is insufficient vapour pressure between the inside and outside air to cause any significant diffusion through the walls and so the calculations are shown for winter conditions only.

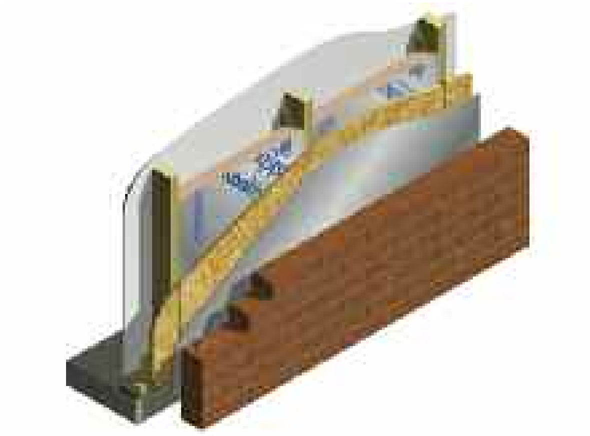
4.6 The calculations assume brick clad timber frame wall constructions of three varying specifications that achieve a U-value of 0.3 W/m^2·K.

Key assumed building dimensions are shown below.

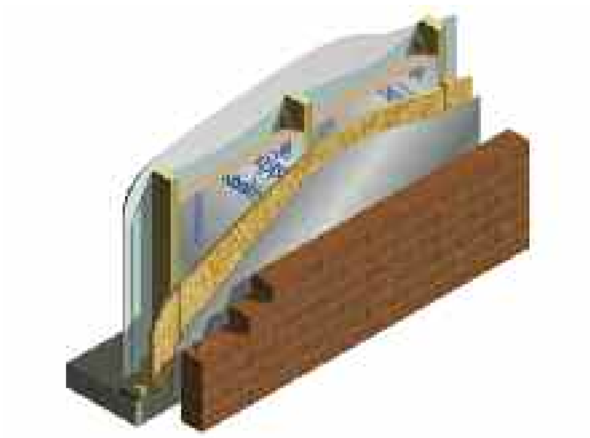
Floor area = 80 m^2.
Wall area = 77.4 m^2.
Building volume =188 m^3.



Wall 1 - Breathable Wall Insulated with 140 mm of Mineral Fibre Between 140 mm Deep Studs



Wall 2 - Mineral Fibre and Studs Replaced with 75 mm of Rigid Phenolic Insulation Between 89 mm Deep Studs



Wall 3 - Polythene Vapour Control Layer Added to Rigid Phenolic Insulated Wall

4.7 The first set of calculations assume a bulk air-exchange rate of 0.5 air changes per hour, which is normally assumed to be the lowest acceptable bulk air-exchange rate for continuous occupancy of a building. This figure was chosen as it represents the worst case for moisture transfer by bulk air-exchange, i.e. the lowest possible bulk air-exchange rate and thus the lowest possible moisture transfer via this route.

	Total Vapour Resistance of Walls (MN·s/g)	Calculated Internal Relative Humidity	Vapour Transfer by Diffusion
Wall 1	8	74%	5.0%
Wall 2	111	75%	0.4%
Wall 3	611	75%	0.1%

It can be seen that the vapour resistance of the wall makes very little difference to the relative humidity inside the dwelling. Even with the most vapour-open wall, vapour diffusion accounts for only 5% of the vapour transfer.

4.8 The second set of calculations assumes that the bulk air-exchange rate will be set at a level designed to yield a relative humidity of 65% inside the building. This relative humidity is chosen as it represents the maximum relative humidity above which dust mite populations become problematic.

	Total Vapour Resistance of Walls (MN·s/g)	Ventilation Rate (air changes / hour)	Vapour Transfer by Diffusion
Wall 1	8	0.81	3.3%
Wall 2	111	0.83	0.2%
Wall 3	611	0.84	0.0%

In order to reduce the relative humidity, for the same external conditions, the bulk air-exchange rate has to be increased by approximately 60%. With the most vapour-open wall, vapour diffusion accounts for only 3.3% of the vapour transfer.

4.9 The calculations demonstrate that vapour diffusion through the wall does not make a significant contribution to the rate of vapour transport.

4.10 The key to creating and maintaining comfortable and healthy indoor conditions lies in good thermal design, linked with adequate provision for bulk air-exchange through controllable ventilation.

5 Claims & Facts

A mineral fibre manufacturer has made specific claims and allegations which Kingspan Insulation believes are inaccurate and can be directly countered with the facts.

Mineral Fibre Manufacturer's **Claim**

"Breathability is important."

Fact: ***Untrue***

Breathability is of little significance. The Cambridge Architectural Research study shows that:

- in summer, moisture vapour transfer is insignificant as the vapour pressure gradient between the inside and outside of buildings is negligible;
- in winter assuming a bulk air-exchange rate of 0.5 air changes an hour (the minimum considered to be healthy), bulk air-exchange accounts for 95% of the vapour transfer in a house with breathable walls;
- if the bulk air-exchange rate is increased to a level that maintains internal relative humidity to 65% (the ideal level to control mould and dust mites), bulk air-exchange accounts for 96.7% of the vapour transfer in a house with breathable walls;
- breathable constructions are therefore at best a side show, in reality they are a complete red herring as the number of houses built today to levels of air-tightness that can theoretically achieve 0.5 air changes an hour are insignificant and effects of occupancy habits (such as opening doors and windows) will render this air-exchange rate mythical in all but the most carefully controlled circumstances - and the higher the air change rate the smaller the impact of breathability.

Mineral Fibre Manufacturer's **Claim**

"The capacity for a building envelope to breathe is a crucial part of maintaining the health of buildings and their inhabitants. Vapour permeable structures are more preferable than vapour-closed structures because they help to preserve the health and performance of the building and its inhabitants. Getting breathability right is an essential part of creating buildings with healthy indoor environments."

Fact: ***Untrue***

Given the above, clearly this is not the case. Bulk air-exchange rates are at least 19 times more significant.

Mineral Fibre Manufacturer's **Claim**

"Buildings that do not perform well in terms of vapour diffusion may develop sick building syndrome and chronically suffer from problems such as mould and damp, which create very unhealthy living and working environments."

Fact: ***Misleading***

Given the above, clearly this is not the case. But it may be true of buildings with poor ventilation. In a building with poor ventilation, and high enough relative humidity for these problems to be manifest, the breathability of a wall is unlikely to allow significant enough vapour transfer to lower relative humidity to a level low enough to negate these problems.

Mineral Fibre Manufacturer's **Claim**

"Breathability has not been given much consideration because of the poor breathability of widely used synthetic building materials."

Fact: *Untrue*

This is untrue. It has not been given much consideration because breathability is insignificant and ventilation is the key. That is why ventilation is an issue considered by Building Regulations and documents such as BR262 "Thermal Insulation Avoiding Risks" but breathability is not.

Mineral Fibre Manufacturer's **Claim**

"If a material such as plastic foam is used as external wall insulation, moisture may become trapped between the interior face of the insulation layer and the building structure, particularly in old buildings where there is residual damp. This could result in a chronically damp wall which.... could develop mould."

External wall insulation installed on a solid brick wall.

Fact: *Misleading*

All masonry will contain a certain amount of moisture, this is true, and if it is then clad in an external wall insulation system then this moisture will be there at the moment that the wall is clad. However, what will happen to that water?

Just because the wall has been clad does not mean that the water will suddenly start to come out of the brickwork and sit between the brickwork and the insulation. The wall will gradually dry out by evaporation and vapour diffusion until it has reached a stable equilibrium with the spaces surrounding it. Vapour diffusion can occur in any direction. Vapour will move from areas of higher relative humidity to lower. So the moisture content of the wall will vary over time depending on the relative humidities of the air on either side. The rate of diffusion will depend on the vapour resistance of the construction in the direction in question.

With a porous insulation material, some of this initial vapour will transfer out through the insulation material and the render and some will transfer to the air inside the building and then be ventilated away. With a cellular plastic insulation material the diffusion will happen to the interior of the building in the same manner but in the external direction there will be less vapour transfer, although there will be some transfer via the joints between boards.

Thus chronic damp is simply not going to happen unless for some reason the relative humidity of the internal air is being kept artificially and extraordinarily high because of extremely low ventilation rates. Mould with an effect on human health would have to form on the inner surface of a wall. Since the moisture content of the inner surface of the wall is in equilibrium with the internal air it is therefore extremely unlikely that mould would form with either high or low vapour resistance insulation again unless the ventilation rate were to be extraordinarily poor.

Mineral Fibre Manufacturer's **Claim**

"If water enters the building fabric as part of the construction process it is better able to escape once the building is complete if breathable insulation...is used. If this process is prevented, trapped water can cause mould and decay, for example, in timbers."

Fact: *Misleading*

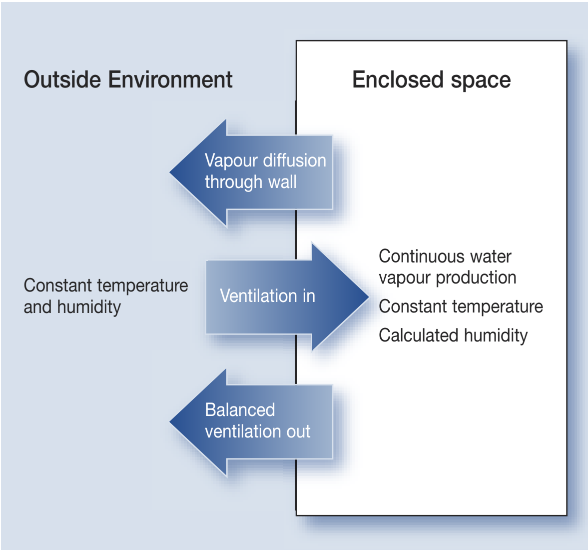
The detailed answer will depend on each individual construction but will be generally very similar to that above. If normally dry construction components e.g timber, blocks and bricks get incidentally wet during construction, their moisture content is not raised to a significantly problematical level for normal drying processes to deal with the moisture. For wet components which contain significant water contents, such as concrete, there are codes of practice that state drying times. Other wet components with significant water contents such as plaster have full access to a ventilated air space to facilitate drying.

Appendix 1

Water Vapour Transfer Model

A simple theoretical model was constructed and standard building physics equations were used to represent the vapour transfer through the walls and by ventilation.

The model comprises two zones with constant external conditions and internal conditions dependant upon the rate of moisture production in the building and the moisture transfers between the zones. It is illustrated below.



A simple algorithm was constructed in Excel examining moisture transfer by diffusion and ventilation. Basic relationships compatible with the CIBSE data for saturated vapour pressure and absolute humidity were employed.

P_{sv} = 610.78 * EXP (t / (t + 238.3) *17.2694); where
P_{sv} = saturated vapour pressure (Pa); and
t = temperature (°C);

and

C_w = 0.002166 * Pp / (t + 273.16); where
C_w = absolute humidity (kg/m^3); and
Pp = vapour pressure (Pa).

Standard mechanisms for mass transfer were applied.

Vapour diffusion through walls:

Q_w = ΔP / s * A; where
A = area of walls (m^2);
Q_w = mass of water transferred (g/s/m^2);
ΔP = difference in vapour pressure across section (Pa); and
s = vapour resistance (MN·s/g).

While vapour transfer by ventilation:

$Q_w = C_w * V_a$ /1000; where
(C_w for the supply air); and
V_a = ventilation rate (m^3/s).

Finally the percent relative humidity is dependant upon the vapour pressures:

RH = Pp / Psv; where
RH = % relative humidity.

And the energy transfer is assumed to be dependant upon the temperature of the ventilation flow:

$Q_v = V_a * c_a * \Delta T$; where
ΔT = temperature difference between internal and external spaces; and
c_a = specific heat of air (J/m^3/K).

Two modes of operation were used. In the first case a fixed ventilation rate was assumed. Water vapour in the building is assumed to reach equilibrium:

Q_w (outside to inside) + Q_w (inside to outside) + Q_w (diffusion through walls) = 0.

However, all the transfer rates are dependant upon the internal relative humidity, which is iteratively adjusted until the net water vapour transfer is zero, for the steady state.

The alternative mode of operation iteratively adjusts the ventilation rate until the net transfer rate is zero of a fixed internal relative humidity.

The excel spread sheet has functions to allow the adjustments to be made automatically.

Sample Calculation for a Fixed Ventilation Rate of 0.5 ach

Parameter	Construction		
	Wall 1	Wall 2	Wall 3
Vapour resistance of walls (MN·s/g)	8	111	611
Ventilation rate (ach)	0.50	0.50	0.50
Ventilation rate (l/s)	26	26	26
External temp (°C)	5	5	5
External relative humidity	95%	95%	95%
External saturation vapour pressure (Pa)	871	871	871
External vapour pressure (Pa)	827	827	827
External absolute humidity (kg/m^3)	0.0064	0.0064	0.0064
Internal temp (°C)	15	15	15
Internal relative humidity	74%	75%	75%
Internal saturation vapour pressure (Pa)	1,698	1,698	1,698
Internal vapour pressure (Pa)	1,249	1,268	1,270
Internal absolute humidity (kg/m^3)	0.0094	0.0095	0.0095
Internal total water (kg)	1.765	1.792	1.794
Ventilation moisture in (kg/hr)	0.61	0.61	0.61
Ventilation moisture out (kg/hr)	-0.88	-0.90	-0.90
Net ventilation moisture (kg/hr)	-0.28	-0.29	-0.29
Moisture generation (kg/hr)	0.29	0.29	0.29
Diffusion through wall (kg/hr)	-0.015	-0.001	0.000
Net transfer (kg/hr)	0.00	0.00	0.00
% diffusion	5.0%	0.4%	0.1%

Sample Calculation for a Fixed Relative Humidity of 65%

Parameter	Construction		
	Wall 1	Wall 2	Wall 3
Vapour resistance of walls (MN·s/g)	8	111	611
Ventilation rate (ach)	0.81	0.83	0.84
Ventilation rate (l/s)	42	43	44
External temp (°C)	5	5	5
External relative humidity	95%	95%	95%
External saturation vapour pressure (Pa)	871	871	871
External vapour pressure (Pa)	827	827	827
External absolute humidity (kg/m^3)	0.0064	0.0064	0.0064
Internal temp (°C)	15	15	15
Internal relative humidity	65%	65%	65%
Internal saturation vapour pressure (Pa)	1,698	1,698	1,698
Internal vapour pressure (Pa)	1,104	1,104	1,104
Internal absolute humidity (kg/m^3)	0.0083	0.0083	0.0083
Internal total water (kg)	1.560	1.560	1.560
Ventilation moisture in (kg/hr)	0.98	1.01	1.02
Ventilation moisture out (kg/hr)	-1.26	-1.29	-1.31
Net ventilation moisture (kg/hr)	-0.28	-0.29	-0.29
Moisture generation (kg/hr)	0.29	0.29	0.29
Diffusion through wall (kg/hr)	-0.010	-0.001	0.000
Net transfer (kg/hr)	0.00	0.00	0.00
% diffusion	3.3%	0.2%	0.0%

Contact Details

Customer Service

For quotations, order placement and details of despatches please contact the Kingspan Insulation Customer Service Department on the numbers below:

UK – Tel: +44 (0) 870 850 8555
– Fax: +44 (0) 870 850 8666
– email: commercial.uk@insulation.kingspan.com

Ireland – Tel: +353 (0) 42 97 54200
– Fax: +353 (0) 42 97 54299
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– Fax: +44 (0) 1544 387 289
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– Fax: +353 (0) 42 97 54296
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– Fax: +44 (0) 1544 387 278
– email: techline.uk@insulation.kingspan.com

Ireland – Tel: +353 (0) 42 97 54297
– Fax: +353 (0) 42 97 54296
– email: techline.ie@insulation.kingspan.com

General Enquiries

For all other enquiries contact Kingspan Insulation on the numbers below:

UK – Tel: +44 (0) 870 850 8555
– Fax: +44 (0) 870 850 8666
– email: info.uk@insulation.kingspan.com

Ireland – Tel: +353 (0) 42 97 54200
– Fax: +353 (0) 42 97 54299
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Kingspan Insulation Ltd
Pembridge, Leominster, Herefordshire HR6 9LA, UK
Castleblayney, County Monaghan, Ireland
www.insulation.kingspan.com