Mould in Buildings: Implications and Causes in Occupied Spaces

12th May 2016 | International Conference on Moisture in Buildings

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UCL Institute for Environmental Design and Engineering
Bartlett School of Energy Environmental and Resources
For the purposes of this Approved Document, the moisture criterion will be met if the relative humidity (RH) in a room does not exceed 70% for more than 2 hours in any 12 hour period, and does not exceed 90% for more than 1 hour in any 12 hour period during the heating season.

Approved Document F, means of Ventilation – The Building Regulations 2000
The number of homes affected with mould, condensation, and damp conditions:

In 1982 was estimated that in England 2 million dwellings (11.8% of all household), were affected by dampness, with condensation being the cause in 60%. Sanders & Cornish

The 1986 English House Condition Survey was estimated that 3.5 million dwellings (20% of all households) experience some mould or damage to decoration due to damp.

The 1991 English House Condition Survey found that 10.4 million homes were affected by mould growth

The 1996 Northern Ireland House Survey found that 16% of homes experience some form of dampness or mould (95,000)

The 1996 English House Condition Survey had found that 15% of all households had scores in the Mould severity index. (2.6 million)

<table>
<thead>
<tr>
<th>Severity of mould growth</th>
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<td>Any room</td>
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The 2011 English House Condition Survey found that 7% of homes had some problems with damp (1.4 million), 3.5% affected by condensation and mould
Mould growing in buildings could have a large effect on:

- Aesthetics of the building
- Cost / maintenance of buildings due to mould related damage
- Health of occupants (Physical and Mental health)
Economic effects

£400 millions – UK (Singh, 1999)
$500 to $30.000 – USA (costhelper, 2008)
£10 millions – 400 dwellings (2015)

$1.2 billions – USA (Hanekamp, 2003)

$3.5 billions annually – USA (Mudarri and Fisk, 2007)

Repairing mould contaminated buildings
Pay out from insurers to solve mould claims (2002 – 10.000 mould related lawsuit)

4.6 millions cases of asthma resulted from exposure to dampness and mould
Health effects?

In the UK ~20% of all households experience mould or dampness

Mould exacerbate or help to develop asthma – 21% of cases in USA attributed to dampness and mould (Mudarri and Fisk, 2007)

In the UK, the prevalence of **respiratory symptoms** and asthma is one of the **highest in the world** (Janson et al. 2001).

Every **ten seconds** someone in the UK has a potentially life-threatening asthma attack and **Three people die** every day. (asthma UK)
Mould produce **mycotoxins** designed for chemical warfare against other organisms (plants, bacteria and even against other types of mould)

Mycotoxins are also substances that can cause a range of respiratory and non-respiratory problems to humans

The ways in which mould induces illness have been categorized in three main mechanisms:

• **Sensitivity reactions**
  (allergies or hypersensitivity reactions)

• **Biochemical reactions**
  (physiological alteration of the body – cell or tissue functions)

• **Mycotic infections**
A few of the possible symptoms of mould allergy:
Nasal Congestion, Irritation of the eyes, Inflammation of the sinuses, Irritation of the skin, Breathlessness, Headache, Runny nose, Fatigue, Cough, Sore throat, Hoarseness

More serious symptoms
You may develop a skin rash, Can induce serious respiratory problems, May cause wheezing or shortness or breath, Inflammation of the ear, Bleeding Lungs, Nose Bleeds, Memory Loss Arthralgia (Pain in the joints without swelling) Flu like symptoms such as nasal stuffiness, fever, headaches, abdominal pain and diarrhea.
Mental effects

**Depression symptoms:** sleeping problems and decrease in appetite (Shenassa et al., 2007)

**Common mental disorder:** anxiety disorder, depressive episode, phobias, obsessive compulsive disorder, panic disorder, and mixed anxiety and depression (McManus et al., 2009)
How to prevent mould growth in buildings?
Orchid / Orchidaceae
22,000 and 26,000 species
1,000,000
Mould species

100,000
Mould Genera (genus)
29 Million people in the US
(Oh J. et al Conlan S, Polley EC, Segre JA and Kong HH, 2012)
Mould are organisms that play an important role breaking down and digesting organic material.
Penicillin was being mass-produced in 1944. During World War II, Penicillin made a major difference reducing considerably (12%–15%) the number of deaths and amputations caused by infected wounds among Allied forces.
Stilton cheese - *Penicillium glaucum*

Roquefort cheese - *Penicillium roqueforti*

Soy sauce – *Aspergillus oryzae*

Miso – *Aspergillus oryzae*

Spanish Chorizo - *Penicillium nalgiovense*
Cordyceps species

Images from: http://www.youtube.com/watch?v=bkvRFK3CSU
Mould life cycle

- Sporulation
- Vegetative growth
- Germination

Nuclear Migration in Growing Germlings of

Image source: www.bodley.ox.ac.uk
Condition required to growth

- **pH**
- **Light**
- **Oxygen**
- **Nutrients**
- **Temperature**
- **Water**
Condition required to growth

Relative Humidity (RH)
- Highly hydrophilic (wet loving)
- Moderately hydrophilic
- Moderately xerophilic
- Xerophilic
- Highly xerophilic (dry loving)

Water activity or equivalent RH (ERH) ($a_w$)

Limiting growth curves and moisture bands

Germination
Vegetative growth
Sporulation

Lower envelope curves, according to Clarke (13) and Sedlbauer dissertation.

$$a_w = \frac{RH}{100}$$

$$0.75 \, a_w = 75\%$$
Isopleth systems for spore germination of the mould fungi Aspergillus restrictus (on the left) and Aspergillus versicolor (on the right).

Isopleth systems for mycelium growth of the mould fungi Aspergillus restrictus (on the left) and Aspergillus versicolor (on the right).

Germination, mycelium growth and sporulation - Penicillium chrysogenum

Germination, mycelium growth and sporulation - Aspergillus versicolor.
Water? From where?

Nonhousehold sources
- Plumbing leaks
- Floods
- Rain penetration
- Raising water – ground moisture migration
- New construction materials
- Seasonal high outdoor absolute humidity

Household sources
- People (depending on activity)
- Plants
- Bathrooms (showers – baths)
- Kitchen (cooking)
- Fuels
- etc…..
How to prevent mould growth in buildings?

Controlling moisture

Relative humidity and water activity
1. Reducing moisture produced indoors
1. Reducing moisture produced indoors

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</tr>
<tr>
<td>People Active</td>
<td>55 g/h per person</td>
</tr>
<tr>
<td>Cooking Electricity</td>
<td>2000 g/day</td>
</tr>
<tr>
<td>Cooking Gas</td>
<td>3000 g/day</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>400 g/day</td>
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<tr>
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Typical moisture generation rates for household activities (BS5250:2002)

Source: http://www.gettyimages.co.uk/creative/condensation-stock-photos#6
Source: http://emilywallis.com
2. Improving ventilation

**Natural Ventilation**
- Cross ventilation
- Singled sided ventilation
- Stack ventilation
- Combined cross and stack ventilation

**Mechanical ventilation**
- Mechanical extract ventilation
- Local extract fans
- Continuous mechanical extract

3. Increasing air and surface temperatures

- Providing more insulation
- If required, increasing heat inputs
- Limiting thermal bridging
External insulation behind soil pipe
Moisture criteria to avoid mould growth (ADF 2010)

“There should be no visible mould growth on external walls. For the purpose of this Approved Document, the moisture criterion will be met if the average relative humidity (RH) in a room is less than the following during the heating season:
Moisture criteria to avoid mould growth (ADF 2010)

**All dwellings (new, and existing)** the moisture criterion is likely to be met if the moving average surface water activity of the internal surfaces of external walls is always less than the value noted below:

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</tr>
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Water activity ($aw$) = \( \frac{\text{Relative humidity (RH)}}{100} \)

average Surface water activity ($aw$) = \( \frac{\text{average Surface relative humidity (RH)}}{100} \)

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</tr>
<tr>
<td>1 week</td>
<td>75%</td>
</tr>
<tr>
<td>1 day</td>
<td>85%</td>
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</table>

+10%
Summary

Moisture in buildings is a **complex** and still an unresolved problem.

Mould growth

- Reducing moisture produced indoors
- Improving ventilation
- Increasing air and surface temperatures

Image source: English Heritage 2011
Relevant publications


Humidity
The number of water vapour molecules in the air

Absolute humidity
Is the mass of water vapour in a unit of volume of air. It is a measure of the actual water vapour content of the air (kgm$^3$)

Vapour pressure
Is the actual water vapour in the air or the partial pressure of the water vapour (Pa, KPa, mb)

Saturated vapour pressure
The maximum water vapour the air can holds

Relative humidity
The ratio of the actual amount of water vapour in the air to the amount it could hold when saturated expressed as percentage

Dew-point
The temperature to which air must be cooled for saturation to occur
Moisture criteria to avoid mould growth (ADF 2010)

Relative humidity on surfaces (\(RH_s\)) is calculated using the saturated vapour pressure (\(E_s\)) for the predicted surface temperature (\(\theta_s\)), and saturated vapour pressure (\(E_{dp}\)) for the dew point temperature (\(\theta_{dp}\)) given when applying the equations below and boundary condition of outdoors temperature = 0°C (\(\theta_e\)), indoor temperature = 20°C (\(\theta_i\)) and an internal relative humidity of 50% (\(RH_i\)).

\[
E_s = 6.11 \times 10^7 (7.5 \times \theta_s/(237.7+\theta_s))
\]
\[
E_{dp} = 6.11 \times 10^7 (7.5 \times \theta_{dp}/(237.7+\theta_{dp}))
\]

\[
RH_s = E_s / E_{dp} \times 100
\]

Table 2. Moisture criteria for mould growth prevention (HMSO, 2010)

<table>
<thead>
<tr>
<th>Period</th>
<th>Surface a.w.</th>
<th>Room air RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>0.75</td>
<td>65%</td>
</tr>
<tr>
<td>1 week</td>
<td>0.85</td>
<td>75%</td>
</tr>
<tr>
<td>1 day</td>
<td>0.95</td>
<td>85%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RH_i</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>dew point ((\theta_{dp}))</td>
<td>9.25</td>
<td>11.99</td>
<td>14.36</td>
</tr>
<tr>
<td>surf Temp ((\theta_i))</td>
<td>18.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ext term</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Int temp</td>
<td>20</td>
<td></td>
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Temperature factor 0.94
TDR 0.065

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<tr>
<th>(E_s)</th>
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<tr>
<td>21.5</td>
<td></td>
<td></td>
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<td>11.7</td>
<td>14.0</td>
<td>16.3</td>
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Surface humidity (\(RH_s\)) 54.2 65.0 75.9
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THE LUNGS

- Nasal Cavity
- Oesophagus
- Trachea
- Bronchus
- Heart
- Ribs
- Lungs
- Diaphragm
- ABDOMEN
- Carbon Dioxide Out
- Oxygen In

Deposition per airway generation (%)

Source: Richard Lewis, airpath presentation
Mental effects

**Depression symptoms**: sleeping problems and decrease in appetite (Shenassa et al., 2007)

**Common mental disorder**: anxiety disorder, depressive episode, phobias, obsessive compulsive disorder, panic disorder, and mixed anxiety and depression (McManus et al., 2009)
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Cordyceps species

Images from: http://www.youtube.com/watch?v=bkvRJKXSU
Mould life cycle

- Sporulation
- Vegetative growth
- Germination

Nuclear Migration in Growing Germlings of
Condition required to growth

- **Aspergillus repens** IMI 94150
- **Aspergillus versicolor** IMI 127256
- **Ulocladium consortiale** IMI 80003
- **Cladosporium sphaerospermum** IMI 84420
- **Aspergillus niger** IMI 00001
- **Penicillium chrysogenum** IMI 184732

**Condition required to growth**:
- pH
- Oxygen
- Light
- Nutrients
- Temperature
- Water
Condition required to growth

Relative Humidity
RH

Sporulation

Vegetative growth

Germination

a_w
Water activity or equivalent RH (ERH)

\[ a_w = \frac{RH}{100} \]

0.75 \( a_w \) = 75%

Limiting growth curves and moisture bands

Lower envelope curves, according to Clarke (13) Sedlauer dissertation.
Isopleth systems

Isopleth systems for spore germination of the mould fungi Aspergillus restrictus (on the left) and Aspergillus versicolor (on the right)

Germination, mycelium growth and sporulation - Penicillium chrysogenum

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- Plumbing leaks
- Floods
- Rain penetration
- Raising water – ground moisture migration
- New construction materials
- Seasonal high outdoor absolute humidity

Household sources
- People (depending on activity)
- Plants
- Bathrooms (showers – baths)
- Kitchen (cooking)
- Fuels
- etc……
How to prevent mould growth in buildings?

Controlling moisture

Relative humidity and water activity

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Natural Ventilation
- Cross ventilation
- Singled sided ventilation
- Stack ventilation
- Combined cross and stack ventilation

Mechanical ventilation
- Mechanical extract ventilation
- Local extract fans
- Continuous mechanical extract

![Diagram showing improving ventilation methods](image)

Ventilation rates to control pollutants (energy efficient ventilation in dwellings – a guide for specifiers (2006 edition))

- Minimise moisture build-up: 1 ach
- Control V/OC: 1 ach
- Control body odour: 1 ach
- Control CO during cooking: 1 ach
- Oxygen: 0.15 L/second/person

CIBSE AM10 and ASHRAE Standard 62.1 - 2010
3. Increasing air and surface temperatures

- Providing more insulation
- If required, increasing heat inputs
- Limiting thermal bridging
External insulation behind soil pipe

30 mm insulation behind soil pipe

10 mm insulation behind soil pipe

10 mm gap (un-insulation) behind soil pipe
Unintended consequences
Moisture criteria to avoid mould growth (ADF 2010)

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average Surface water activity = \( \frac{\text{average Surface relative humidity (RH)}}{\text{average}} \)

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Mould growth

• Reducing moisture produced indoors
• Improving ventilation
• Increasing air and surface temperatures
Relevant publications


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Is the mass of water vapour in a unit of volume of air. It is a measure of the actual water vapour content of the air (kgm³)

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Relative humidity
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Dew-point
The temperature to which air must be cooled for saturation to occur
Moisture criteria to avoid mould growth (ADF 2010)

Relative humidity on surfaces (RH_s) is calculated using the saturated vapour pressure (E_s) for the predicted surface temperature (θ_s), and saturated vapour pressure (E_dp) for the dew point temperature (θ_dp) given when applying the equations below and boundary condition of outdoors temperature = 0°C (θ_e), indoor temperature = 20°C (θ_i) and an internal relative humidity of 50% (RH_i).

\[ E_s = 6.11 \times 10^\left(7.5 \times \frac{\theta_s}{(237.7 + \theta_s)}\right) \]
\[ E_{dp} = 6.11 \times 10^\left(7.5 \times \frac{\theta_{dp}}{(237.7 + \theta_{dp})}\right) \]

\[ RH_s = \frac{E_s}{E_{dp}} \times 100 \]