Determining the Acceptable Ranges of Relative Humidity and Temperature in Museums and Galleries

Marion F. Mecklenburg
Smithsonian Museum Conservation Institute

Oslo, Norway, 2010
Looking at the Bigger Picture

There is no single environment that works for everything in the collections
Focus of this talk

- Biological attack
- Physical properties
- Deliquescent salts
- Ceramics
- Building condensation
- Bronze disease
- Cellulose
- Protein Bone
- Pyrite oxidation
- Unstable glass
- Mineral hydrates

Relative Humidity, %
The easiest way to look at the effects of relative humidity on painted wood systems is to look at the dimensional properties and the moisture coefficients.

This approach is only a qualitative first approximation.
New Scotch Pine, The Three Primary Directions

Free Swelling Strains

Relative Humidity(%)
The coefficients of materials are the slopes of these plots or:

\[ \Delta \text{Strains} / \Delta \text{RH} \]
Cottonwood, Tangential Coefficients

Cottonwood, Radial Coefficients

Moisture Coefficients

Relative Humidity (%)

Longitudinal
Gesso, Both Have PVC = 71%, B has Molasses
10 Year Old White Lead in Cold Pressed Linseed Oil

Progressive Shrinkage
20 Year Old Burnt Umber in Linseed

Progressive Swelling

- Free Swelling Strains
- Relative Humidity (%)
Different Material Coefficients

30% RH to 60% RH
Different Material Coefficients

30% RH to 70% RH
Historically there has been considerable confusion and controversy with regards to determining the correct temperature and relative humidity settings for museums and galleries.

Few were able to say with any certainty what caused damages in any specific object. There has certainly been anecdotal reports but rarely were specific details available.

For example, let’s look at a few damaged objects.
20th Century musical instrument with cracked varnish on wood substrate.
20th century American landscape, oil on canvas.

George Parker, Untitled, (Lower Ausable Lake at Indian Head), American, 1911, 48in. x 35.5in. (Photo by James Hamm and courtesy of the Adirondack Museum in Blue Mountain Lake, N.Y.)
19th century American landscape, oil on canvas.
20th century American abstract, oil and acrylic on canvas.

(Photo by James Hamm and courtesy of the owner)
All of the objects just seen were damaged by exposure to low temperatures and RH played no role at all.

The reason these objects were damaged by low temperature is because all oil, alkyd and acrylic paints have low glass transition temperatures. If the ambient temperature falls enough below the glass transition temperature, the paint layers will crack.
Temperature Behavior
In general the thermal coefficients for woods are very low. The Wood Handbook defines thermal coefficients in the radial and tangential directions as functions of their density. Higher densities mean higher thermal coefficients.
Naple's Yellow, Equil. Stress Strain Tests

5%RH, -3C

5%RH, 23C

48%RH, 23C

Thermal Stresses

Relative Humidity Stresses
13.5 Year Old Liquitex Cobalt Blue, Acrylic Emulsion

-8.1°C, 35% RH
-4.1°C, 38% RH
-1.4°C, 49% RH
3.4°C, 47% RH
5.6°C, 40% RH
8.5°C, 50% RH
15.1°C, 56% RH
24°C, 52% RH

Strain
Detail, 20th century English Abstract, oil on canvas.

(Photograph courtesy of Richard Saltoun and taken by Steve Gayler)
The prior painting was damaged by rolling and neither temperature or relative humidity played any role in the damage.

The reason the damage was so extensive with interlayer cleavage was that zinc oxide was mixed with the lead carbonate in the oil. Zinc is notorious for cracking and delaminating.

(Research on the mechanical properties of artists paints at the SI, MCI)
Other factors
The effects of naturally occurring manganese

Different Burnt Umber Paints

- 18.3% Mn
  W&N, 25 Years
  Old Artists' Oils
- 11.7% Mn
  W&N, 7 Years
  Newer Artists' Oils
- 19.1% Mn
  Grumbacher, 7 Years
- 9.1% Mn
  Gamblin, 7 Years
- 1.3% Mn
  Grumbacher, 28 Years
- Control, CPLÖ, 7 Years
- No Mn

Strain
In order to show exactly how objects respond mechanically to different environmental changes, it is necessary to first look at the individual materials used in their construction.

There are three types of tests needed to define the materials:

1. The dimensional response to changes in RH and temperature.
2. The stress-strain test.
3. The restrain and desiccate (or cool) test.
Testing the dimensional response of materials to changes in RH.
Wood’s dimensional response to moisture.

17th. Century Scotch Pine, Tangential Direction

(.00071 / % RH)

Intermediate (30% to 65% RH)
Measurement (.000417 / % RH)
Measuring the mechanical properties of materials; the stress strain test.
The stress strain test: **Stress** is force divided by the cross-sectional area of the sample and **Strain** is the change in the sample length divided by its original length.

![Graph showing stress strain behavior](image-url)
Review of the definitions of the mechanical properties

American Mahogany, 48% RH, Unload test, Tangential direction

Strain

Elastic Region
Plastic Region
Initial Yield Point
New Strain Hardened Yield Point
Initial Modulus
Final Modulus
New Elastic Strain = 0.007 mm/mm
Measuring the stresses (or forces) when materials are under restraint and the environment is changing.

Woods glued cross-grained develop mutual restraint to dimensional response with changes in either temperature or RH.
Wood samples restrained in a changing environment.
Samples of hide glue restrained and desiccated.
Connecting the Three Tests
Relating the tests is required. For example: How are the strains in the stress strain test related to the strains in the dimensional response test?

From an environmental perspective
The magnitude of the strains in the stress strain test are identical to the magnitude of the strains in the dimensional response test.*

Under true equilibrium conditions, all three tests:

1. The stress-strain test
2. The swelling test
3. And the restrained test
   can be related.
Establishing Criteria for Determining RH Boundaries
Setting initial assumptions and criteria for determining the allowable RH for rigid objects, this includes furniture, ivory, panel paintings, painted wood, etc.

1. All materials in the objects in the collections are assumed to be fully restrained from any movement.

2. The strain in any material in any object is not to exceed the yield strain in either tension or compression.

3. There can be initial stresses in the materials in the object.

4. There are no cracks in the objects.
Determining the allowable RH using the established criteria.
Cotton Wood, Tangential Direction

Current SI Guidelines
37% RH to 53% RH

Allowable RH Range
30% RH to 62% RH

Relative Humidity (%)

 +/- 0.005
Effects of conditioning to very high Relative Humidity

Cotton Wood, Tangential Direction

Relative Humidity (%)
It would be expected that all oil paints get stiffer and stronger as time goes on.

Basic lead carbonate in cold pressed linseed oil

- 14.25 Years old
- 10.0 Years old
- 0.98 Years old
- 0.27 Years old
- 0.18 Years old

Strain = 0.005
Oil paints made with white pigments such as basic lead carbonate, titanium dioxide and zinc oxide remain fairly stable in changing relative humidity.

10 year old white lead in cold pressed linseed oil

Allowable range
The use of safflower oil ultimately demonstrates adverse effects. The strength is decreasing and the strain to failure is decreasing. Safflower oil makes a weaker paint than when using cold pressed or alkali refined linseed oil.
20 year old titanium white in safflower oil

Allowable range
Clay in the natural earth colors causes significant swelling from relative humidity.

Even with a desiccation from 60% RH to 30% RH, the change is only 0.005.
The effects of high humidity on the different pigments

19th Cent. Italian, oil on canvas. Damage is due to high moisture levels

Earth Colors

White lead
Analytical tools

Computer modeling
- European poplar
- Gesso layer
- Two layers of oil paint
- RH change from 50% to 30%
- Full equilibrium

Maximum deformation: 1.198 mm
Longitudinal direction

Radial direction

Max Stress = 1.986 MPa

MPa

150mm x 150mm Cottonwood with Gesso, Wt Ld, Nap Yel, Rad. Del RH 50-30
Gesso layer, maximum stress in the longitudinal direction is 1.986 MPa.
It is now possible to compare actual material test data to the computer model results.
Gentile da Fabriano, Marchigian, c. 1370-1427, Madonna and Child Enthroned, c 1420, Tempera on panel, 37 11/16 in. × 22 ¼ in. (95.7 x 56.5 cm), Samuel H. Kress Collection, 1939.1.255. (Courtesy of the National Gallery of Art, Washington, D.C.)
All of the cracks originated in the gesso layer and are perpendicular to the grain of the wood. The environmental ranges in RH had to have exceeded 70% to 20% for this damage to occur. The wood is acting as a restraint to the gesso layer.
Fra Lippo Lippi and workshop, Florentine, c. 1406-1469, The Nativity, probably c 1445, oil and tempera (?) on panel, 9 1/8 in. x 21 3/4 in. (23.2 x 55.3 cm), Samuel H. Kress Collection, 1939.1.279. (courtesy of the National Gallery of Art, Washington, D.C.)
All of the cracks originated in the gesso layer and are perpendicular to the grain of the wood. The environmental ranges in RH had to have exceeded 70% to 20% for this damage to occur. The wood is acting as a restraint to the gesso layer.
For those materials that are fully restrained and are allowed a strain variation of +/- 0.005, with an initial stress of zero, the RH range results are as follows.

<table>
<thead>
<tr>
<th>Material</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woods in general</td>
<td>30-32%</td>
<td>62%</td>
</tr>
<tr>
<td>Hide glue</td>
<td>30%</td>
<td>60%</td>
</tr>
<tr>
<td>Ivory</td>
<td>26%</td>
<td>67%</td>
</tr>
<tr>
<td>Gesso</td>
<td>18%</td>
<td>72%</td>
</tr>
<tr>
<td>White Lead Paint</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Titanium White Paint</td>
<td>28%</td>
<td>66%</td>
</tr>
<tr>
<td>Zinc White Paint</td>
<td>16%</td>
<td>63%</td>
</tr>
<tr>
<td>Earth Color Paints</td>
<td>30%</td>
<td>64%</td>
</tr>
</tbody>
</table>

For those materials fully restrained and already under stress:

<table>
<thead>
<tr>
<th>Material</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woods</td>
<td>30%</td>
<td>80%</td>
</tr>
<tr>
<td>Gesso</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>Linen</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>Hide glue</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>White lead Paint</td>
<td>20%</td>
<td>75%</td>
</tr>
<tr>
<td>Naples Yellow Paint</td>
<td>20%</td>
<td>75%</td>
</tr>
</tbody>
</table>
If constraint of materials and large humidity swings occur together then damage will result.
If you have any questions contact me at mecklenburgm@si.edu

For additional information see the following links.

http://www.si.edu/mci/downloads/reports/Mecklenburg-Part1-RH.pdf
http://www.si.edu/mci/downloads/reports/Mecklenburg-Part2-Temp.pdf