Modelling of air quality for paintings in microclimate frames and

Experiences of the Norwegian Institute for Air Research (NILU) in providing “Air Quality Services for Cultural Heritage Professionals”

Indoor Air Quality, IAQ 2010
Chalon-sur-Saône, 22nd April 2010
Contents

1. Measurements and **modelling** of gaseous pollutants in microclimate frames for paintings.

2. The protection effect of a range of microclimate frames for paintings.

3. **NILU** - Services for Cultural Heritage Professionals
Painting degradation
Worst case?

- Painted about 1935
- Moved to "worse" climate in 1995

New damage appeared
Gaseous pollutants in mc-frames

Inside emission:
- VOCs:
  - Acetic acid
  - Formic acid
  - Formaldehyde
  - H$_2$S

Infiltration from outside (outdoor – room):
- NO$_2$, O$_3$, SO$_2$, H$_2$S etc.
"Impact pollutant flux” to painting

\[ F_0 (ox + ac) = F_0 (NO_2 + O_3) + F_0 (Form.ac + Ac.ac) \]

Infiltrating

Mainly emitted inside mc-frame

Recomended levels

\( C_{T1} (NO_2 + O_3) = 2 \, \mu g \, m^{-3} \)

\( C_{T2} (Acetic + formic acid) = 100 \, \mu g \, m^{-3} \)

\[ F = v_d \times C(\lambda) \]

\[ C_i = \frac{\lambda f VC_0}{\lambda V + v_{do} A_o + v_{df} A_f} + \frac{e A_e + HV}{\lambda V + v_{do} A_o + v_{df} A_f} \]
Procedure

Measurements:

- Ventilation rate (air exchange) (CO$_2$ method)
- Inside and outside concentrations (Passive diff. samplers)
- Mc-frame geometry (Volume, Internal frame and object area)

Calculation:

- Impact fluxes to the painting
- Inside frame emission rates
- Inside deposition velocity
MICRO-CLIMATE FRAME POLLUTION EVALUATION

Recommended levels (µg m⁻³)

- NO₂ + O₃
- Acetic + formic acid

INPUT

Frame geometry

- Volume (m³)
- Internal mc-frame area (m²)
- Object area (m²)
- Air exchange rate (d⁻¹)

Pollutant gas 1 (O₃ + NO₂, - usually infiltrating)

- External concentration (µg m⁻³)
- Internal concentration (µg m⁻³)

Pollutant gas 2 (Acetic + formic acid, - mainly inside emission)

- External concentration (µg m⁻³)
- Internal concentration (µg m⁻³)

Design evaluation

- New volume addition (include minus = "-" if negative)
- New changed volume
- Added area of total absorber (e.g. activated carbon) (m²)
- Absorber multiple of internal frame deposition velocity
- Air exchange interval (d⁻¹)

Result (SUM - Gas 1+2) (µg m⁻² d⁻¹)
## Frame - data

### INPUT
**Frame geometry**

<table>
<thead>
<tr>
<th></th>
<th>Frame no 1 (NG)</th>
<th>Frame no 2 (KH)</th>
<th>Frame no 3 (NMK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>0.013</td>
<td>0.041</td>
<td>0.32</td>
</tr>
<tr>
<td>Internal frame area (m²)</td>
<td>0.71</td>
<td>1.13</td>
<td>1.48</td>
</tr>
<tr>
<td>Object area (m²)</td>
<td>1.3</td>
<td>1.8</td>
<td>0.62</td>
</tr>
<tr>
<td>Air exchange rate (d⁻¹)</td>
<td>0.67</td>
<td>1.4</td>
<td>14.9</td>
</tr>
</tbody>
</table>

**Pollutant gas 1 (O₃ + NO₂)**
- Usually infiltrating

<table>
<thead>
<tr>
<th></th>
<th>Frame no 1 (NG)</th>
<th>Frame no 2 (KH)</th>
<th>Frame no 3 (NMK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External concentration (µg m⁻³)</td>
<td>38</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Internal concentration (µg m⁻³)</td>
<td>1.5</td>
<td>2.5</td>
<td>5.3</td>
</tr>
</tbody>
</table>

**Pollutant gas 2 (Acetic + formic acid)**
- Mainly inside emission

<table>
<thead>
<tr>
<th></th>
<th>Frame no 1 (NG)</th>
<th>Frame no 2 (KH)</th>
<th>Frame no 3 (NMK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External concentration (µg m⁻³)</td>
<td>29</td>
<td>63</td>
<td>33</td>
</tr>
<tr>
<td>Internal concentration (µg m⁻³)</td>
<td>260</td>
<td>2058</td>
<td>317</td>
</tr>
</tbody>
</table>
Kenwood House – UK (Claude de Jongh)

Broken Al-foil seal

Impact flux to painting - NO2 + O3 impact equivalents

Air exchange rate (d⁻¹)

SUM - Gas 1+2
Total - Gas 1 (Photooxidising, O3 + NO2)
Infiltration - Gas 1
Emission + reaction - Gas 1
Total - Gas 2 (Organic acids, acetic + formic)
Infiltration - Gas 2
Emission + reaction - Gas 2
Unprotected by mc-enclosure
Threshold level (in mc-frame)
Threshold level (in room)
VERTICAL
Measured air exchange rate (d⁻¹)
Optimal air exchange rate (d⁻¹)
+ Absorber = 11.3 dm²
   (= 1* internal area)

Impact flux to painting - NO₂ + O₃ impact equivalents
(µg m⁻² d⁻¹)

Air exchange rate (d⁻¹)

SUM - Gas 1+2
Total - Gas 1 (Photoxidising, O₃ + NO₂)
Infiltration - Gas 1
Emission + reaction - Gas 1
Total - Gas 2 (Organic acids, acetic + formic)
Infiltration - Gas 2
Emission + reaction - Gas 2
Unprotected by mc-enclosure
Threshold level (in mc-frame)
Threshold level (in room)
Measured air exchange rate (d⁻¹)
Optimal air exchange rate (d⁻¹)
Frame volume reduced to half

Impact flux to painting - NO2 + O3 impact equivalents

Air exchange rate (d⁻¹)

SUM - Gas 1+2
Total - Gas 1 (Photoxidation)
Infiltration - Gas 1
Emission + reaction - Gas 1
Total - Gas 2 (Organic acids, acetic + formic)
Infiltration - Gas 2
Emission + reaction - Gas 2
Unprotected by mc-enclosure
Threshold level (in mc-frame)
Threshold level (in room)
VERTICAL
Measured air exchange rate (d⁻¹)
Optimal air exchange rate (d⁻¹)
Frame volume reduced 90%
Czartoryski Museum, Krakow (Leonardo)

+ Absorber = 15 dm$^2$
  (= 1* internal area)

Impact flux to painting - NO$_2$ + O$_3$ impact equivalents
($\mu$g m$^{-2}$ d$^{-1}$)

- SUM - Gas 1+2
- Total - Gas 1 (Photooxidis
- Infiltration - Gas 1
- Emission + reaction - Gas 1
- Total - Gas 2 (Organic acids, acetic + formic)
- Infiltration - Gas 2
- Emission + reaction - Gas 2
- Unprotected by mc-enclosure
- Threshold level (in mc-frame)
- Threshold level (in room)

VERTICAL

--- Measured air exchange rate (d$^{-1}$)
--- Optimal air exchange rate (d$^{-1}$)
### Modelling - Results

#### Table 1: Pollution and frame parameters

<table>
<thead>
<tr>
<th>Frame no. (Table 1)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total impact flux in mc-frame (µg m(^{-2}) day(^{-1}))</td>
<td>584</td>
<td>55</td>
<td>436</td>
<td>125</td>
<td>123</td>
<td>108</td>
</tr>
<tr>
<td>Total impact flux in room (µg m(^{-2}) day(^{-1}))</td>
<td>298</td>
<td>407</td>
<td>322</td>
<td>378</td>
<td>329</td>
<td>165</td>
</tr>
<tr>
<td>Total threshold impact flux (µg m(^{-2}) day(^{-1}))</td>
<td>22</td>
<td>21</td>
<td>22</td>
<td>21</td>
<td>42</td>
<td>22</td>
</tr>
<tr>
<td>Flux from infiltration. “Gas 1” (µg m(^{-2}) day(^{-1}))</td>
<td>0.18</td>
<td>0.16</td>
<td>0.53</td>
<td>0.065</td>
<td>56</td>
<td>0.093</td>
</tr>
<tr>
<td>Flux from inside emission. “Gas 1” (µg m(^{-2}) day(^{-1}))</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total inside emission (+ reaction) rate. “Gas 1” (µg day(^{-1}))</td>
<td>2</td>
<td>1.8</td>
<td>0.12</td>
<td>0.11</td>
<td>61</td>
<td>1.4</td>
</tr>
<tr>
<td>Impact flux from infiltration. “Gas 2” (µg m(^{-2}) day(^{-1}))</td>
<td>0.036</td>
<td>0.024</td>
<td>0.023</td>
<td>0.0021</td>
<td>1.2</td>
<td>0.028</td>
</tr>
<tr>
<td>Impact flux from emission. “Gas 2” (µg m(^{-2}) day(^{-1}))</td>
<td>584</td>
<td>55</td>
<td>436</td>
<td>125</td>
<td>66</td>
<td>108</td>
</tr>
<tr>
<td>Real flux from infiltration. “Gas 2” (µg m(^{-2}) day(^{-1}))</td>
<td>1.8</td>
<td>0.12</td>
<td>1.1</td>
<td>0.11</td>
<td>61</td>
<td>1.4</td>
</tr>
<tr>
<td>Real flux from inside emission. “Gas 2” (µg m(^{-2}) day(^{-1}))</td>
<td>29200</td>
<td>2747</td>
<td>21800</td>
<td>6250</td>
<td>3300</td>
<td>5420</td>
</tr>
<tr>
<td>Total inside emission (+ reaction) rate. “Gas 2” (µg day(^{-1}))</td>
<td>54300</td>
<td>5480</td>
<td>63300</td>
<td>13200</td>
<td>8380</td>
<td>16900</td>
</tr>
<tr>
<td>Surface deposition velocity used, object and frame inside (m s(^{-1}))</td>
<td>0.00012</td>
<td>0.00012</td>
<td>0.00012</td>
<td>0.00012</td>
<td>0.00012</td>
<td>0.00012</td>
</tr>
<tr>
<td>Threshold concentration level - “Gas 1” (µg m(^{-3}))</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Threshold concentration level - “Gas 2” (µg m(^{-3}))</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>“Gas 2” – ventilation for threshold concentration below (µg m(^{-3}))</td>
<td>226</td>
<td>150</td>
<td>34</td>
<td>23</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>“Gas 2” – threshold concentration, flux = unprotected flux (µg m(^{-3}))</td>
<td>216</td>
<td>12</td>
<td>137</td>
<td>31</td>
<td>23</td>
<td>55</td>
</tr>
<tr>
<td>“Gas 2” – threshold concentration, flux = threshold flux (µg m(^{-3}))</td>
<td>2736</td>
<td>259</td>
<td>2070</td>
<td>591</td>
<td>imp</td>
<td>505</td>
</tr>
<tr>
<td>Measured ventilation rate (day(^{-1}))</td>
<td>0.19</td>
<td>0.67</td>
<td>1.39</td>
<td>0.15</td>
<td>14.9</td>
<td>0.42</td>
</tr>
<tr>
<td>Optimal (advised) ventilation rate. (day(^{-1}))</td>
<td>ventilate</td>
<td>ventilate</td>
<td>ventilate</td>
<td>ventilate</td>
<td>ventilate</td>
<td>ventilate</td>
</tr>
</tbody>
</table>
## Modelling - Results

### Table

<table>
<thead>
<tr>
<th>Frame no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NO}_2 + \text{O}_3 ) ( (\mu g \text{ m}^{-2} \text{ d}^{-1}) )</td>
<td>0.18</td>
<td>0.16</td>
<td>0.53</td>
<td>0.065</td>
<td><strong>56</strong></td>
<td>0.093</td>
</tr>
<tr>
<td>( (2/100)\ast(\text{Acetic + Formic acid}) ) ( (\mu g \text{ m}^{-2} \text{ d}^{-1}) )</td>
<td>584</td>
<td>55</td>
<td><strong>436</strong></td>
<td>125</td>
<td>66</td>
<td>108</td>
</tr>
<tr>
<td>Threshold ( (\text{Ac + Fo}) = \text{Unprotected} ) ( (\mu g \text{ m}^{-3}) )</td>
<td>216</td>
<td>12</td>
<td>137</td>
<td>31</td>
<td>23</td>
<td>55</td>
</tr>
<tr>
<td>Ventilate ( (V) ) or Seal ( (S) )</td>
<td>( V (?) )</td>
<td>S</td>
<td>( V (?) )</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>
Protection effect of frames vs. rooms (gaseous pollutants)

Tate B and S, NMK1: \(+ (\text{NO}_2 + \text{O}_3 + \text{SO}_2)\) in frame due to high air exchange

Impact concentration in room - frame (\(\mu\text{g m}^{-3}\))

\begin{align*}
\text{MNA} & : & 50 \\
\text{NG} & : & 30 \\
\text{Tate B.} & : & 20 \\
\text{MBV} & : & 10 \\
\text{NRMK1} & : & 10 \\
\text{NMK2} & : & 10 \\
\text{SMK1} & : & 5 \\
\text{EH. K} & : & 5 \\
\text{GNM} & : & 5 \\
\text{Tate S.} & : & 5 \\
\text{Sit Artyd 1} & : & -10
\end{align*}

\(\text{NO}_2 + \text{O}_3\) equiv.
Improved Protection of Paintings during Exhibition, Storage and Transit

http://products.nilu.no

NILU PRODUCTS

Services for Cultural Heritage

Enter Title

NILU Products AS to display newest services at the upcoming UK Museums Association show from October 6th to the 9th in Liverpool, UK. http://www.museumsassociation.org/

Come by and see us in booth 35!

Articles

Phase I

The first phase is to utilize the EWO Dosimeter developed by NILU. The dosimeter reacts in a generic way to the air environment and detects unfavourable conditions before noticeable changes on museum objects can be observed. The dosimeter response gives a direct measure for the acceptability of an environment in various areas from archives to exhibitions. The dosimeter is sensitive to NO₂, O₃, temperature, relative humidity and UV-light and to high concentrations of SO₂ (> 60 ppb). Read More...

Phase II

If Phase 2 is required then we suggest the use of passive samplers to determine the exact cause of the concern. These passive samplers are placed in the same location as the EWO and remain there for one month before being returned to NILU Products for evaluation.

The sample image to the right was created by SVQUM Ltd. to show results of a passive sampler study. Read More...

FAQs

Q. How does the EWO work?
A. See the article above.

Q. How often should we perform these tests?
A. Once a month.

Q. How are the results provided?
A. In a report.

Q. If my results from the EWO Dosimeter are not acceptable then what?
A. Follow the recommendations in the report.

Q. What if contaminants are not detected?
A. The environment is acceptable.

Dust Analysis

In addition, NILU Products can also provide dust testing capabilities...
PROPAINT
end users:

<table>
<thead>
<tr>
<th>No</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SIT - laboratories</td>
</tr>
<tr>
<td>2</td>
<td>Nasjonalmuseet for Kunst, Arkitektur and Design, Oslo, Norway</td>
</tr>
<tr>
<td>3</td>
<td>English Heritage, Apsley House, UK</td>
</tr>
<tr>
<td>4</td>
<td>Tate Store, London, UK</td>
</tr>
<tr>
<td>5</td>
<td>Statens Museum for Kunst, Copenhagen, Denmark</td>
</tr>
<tr>
<td>6</td>
<td>Fine Arts Museum, Valencia</td>
</tr>
<tr>
<td>7</td>
<td>National Museum of Art, Mexico City, Mexico</td>
</tr>
<tr>
<td>8</td>
<td>Germanisches Nationalmuseum, Nürnberg, Germany</td>
</tr>
<tr>
<td>9</td>
<td>National Museum in Krakow, Poland</td>
</tr>
<tr>
<td>10</td>
<td>Uffizi Gallery</td>
</tr>
<tr>
<td>11</td>
<td>Centre for Conservation Science and Restoration Techniques, National Research Institute of Cultural Properties, Tokyo</td>
</tr>
</tbody>
</table>
Thank you!

NILU - Norwegian Institute for Air Research
BIRKBECK College, Department of Chemistry, University of London
Royal Danish Academy of Fine Arts, The School of Conservation
SIT – International Transporters, Madrid, Spain
Fraunhofer Institute for Silicate Research, Bronnbach, Germany
National Museum in Krakow, Poland
Department of Chemistry and Industrial Chemistry, University of Pisa, Italy