IAQ in museums and archives

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9th Indoor Air Quality meeting Chalon-sur-Saone, France

Thenardite-Mirabilite cycles in historical buildings

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Salt Weathering

Under certain environmental exposure conditions, historical buildings and stone monuments are known to exhibit physical salt attack and weathering.

The sources of the salts are attributed to the extensive use of cement-based mortars and concrete in large restoration programmes over the past 50 years, as well as salts from air pollution and rising damp (Arnold & Zender, 1988) .

Soluble salts from cement-based mortars and concrete are still today an important cause of decay to historical building materials (Moropoulou, 2000).

Ordinary porous concrete exposed to soils containing sodium sulfate are known to exhibit salt attack and weathering. Significant scaling occurred when concrete was subjected to numerous cycles of thenardite mirabilite conversion (Haynes et al., 2008)

Thenardite - Mirabilite Cycles

The transition from Thenardite to Mirabilite occurs with the inclusion of 10 molecules of water in the hydrated crystal.

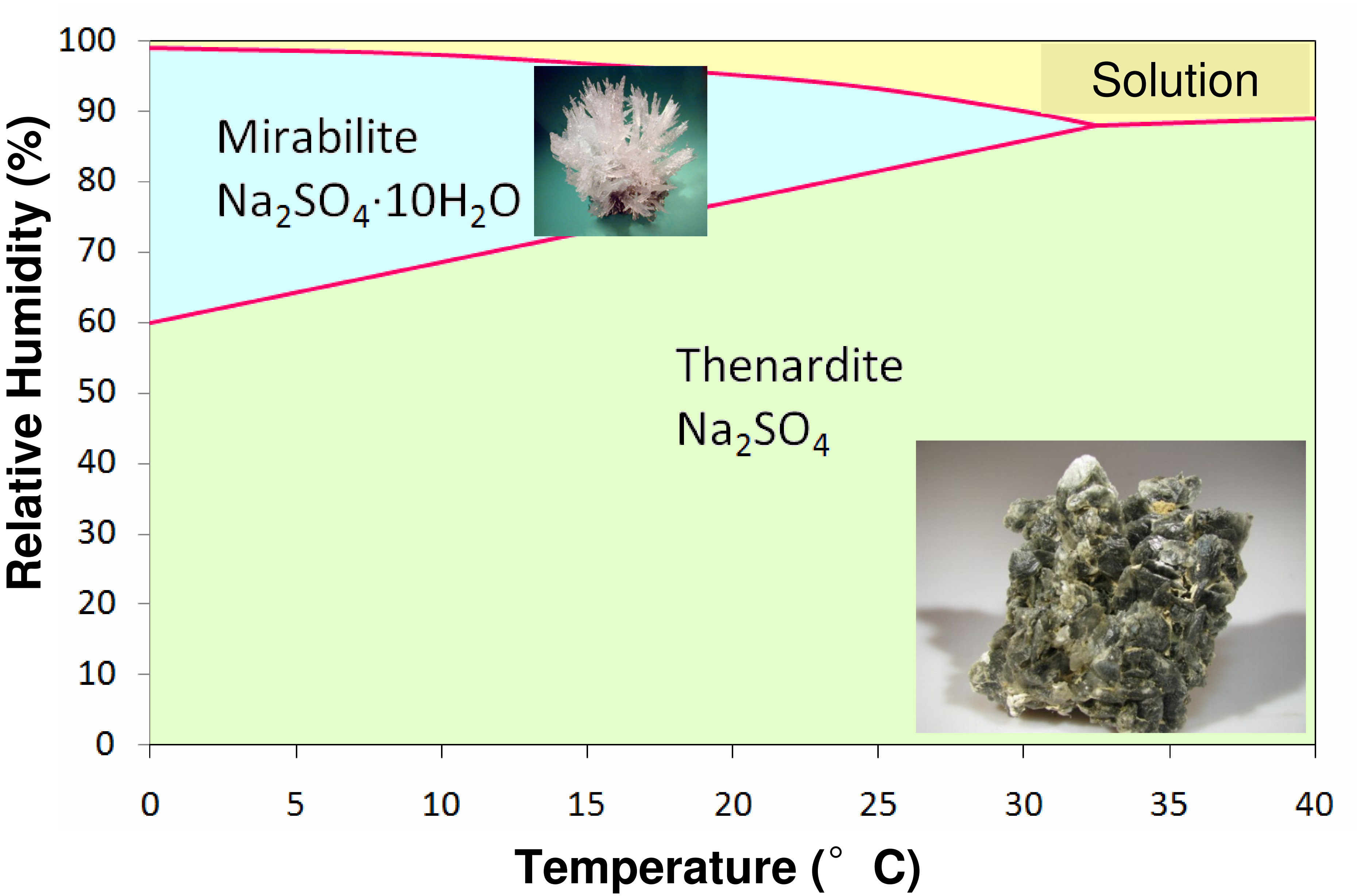
Thenardite $Na_2SO_4 + 10\ H_2O \rightarrow$ Mirabilite

Mirabilite exerts a very high crystallization pressure on the pore wall causing damage of the stone. Moreover, the transient stress can remain for a long period of time since the relaxation process is slow (Espinosa et al., 2008).

Repeated cycles may accumulate stress, and in the long run cause severe decay.

A selective review is reported by Doehne (2002).

Microclimate & Transformation

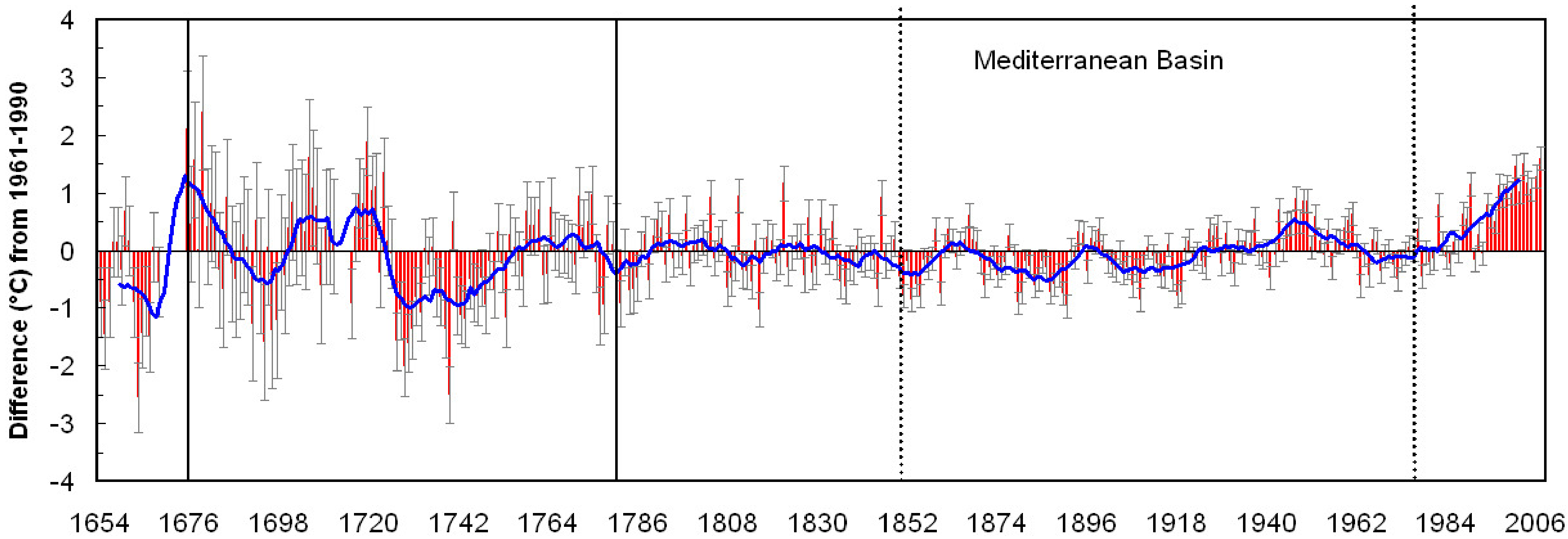



THENARDITE-
MIRABILITE
WEATHERING

Chappelle de la Colombière – Water percolating inside the concrete envelope, pinpointed by efflorescence. Potential risk of damaged structures for thenardite-mirabilite cycles. Hypothesis to be verified.

Outdoor Climate Change

In the last 3.5 centuries, the **outdoor** temperature has increased less than 1° C in the Mediterranean region.



Camuffo et al., *Climatic Change* 2010

Indoor Microclimate Change

Indoors, the change has been much bigger, e.g. +20° C in winter and -10° C in summer. Has been this beneficial or catastrophic?

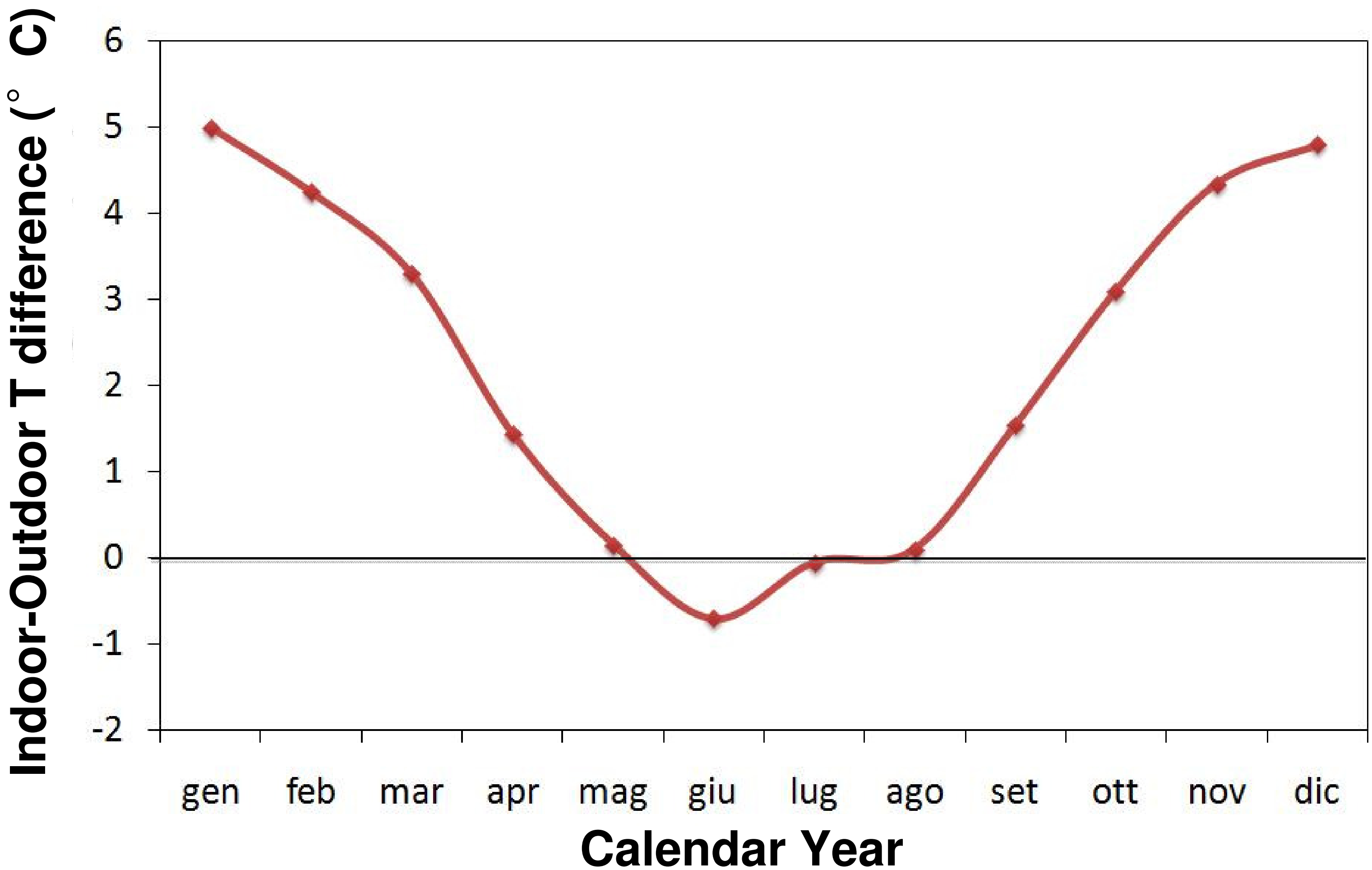
What we know about the historical climate inside the buildings in which artworks have been preserved per centuries and to which they have acclimatized?

Inside heated buildings, crystallization and decay are related to variations in RH primarily caused by heating and, secondarily, by the influence of external weather.

In non heated buildings seasonal variations of microclimate and external weather also induce periodic crystallization cycles.

How the risk of selected deterioration mechanisms (e.g. thenardite/mirabilite transition) changes with the geographic location and climate change?

In an unheated Historical Building, the envelope, the ventilation and the use determine a seasonally variable indoor-outdoor temperature difference.
The difference may reach 5° to 10° C

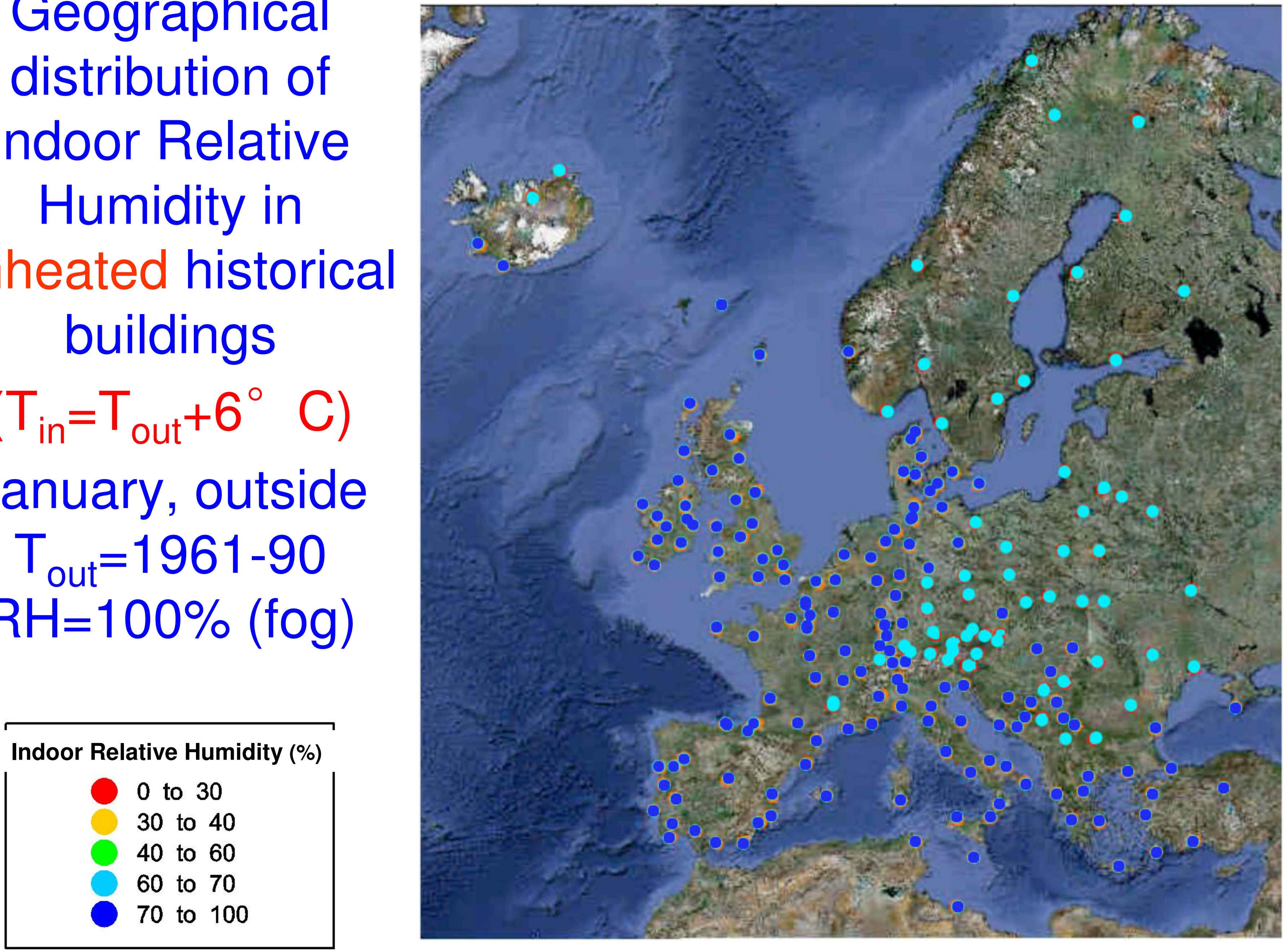


An example of measured indoor – outdoor temperature difference in Northern Italy

Geographical distribution of indoor Relative Humidity in unheated historical buildings

($T_{in}=T_{out}+6°$ C)

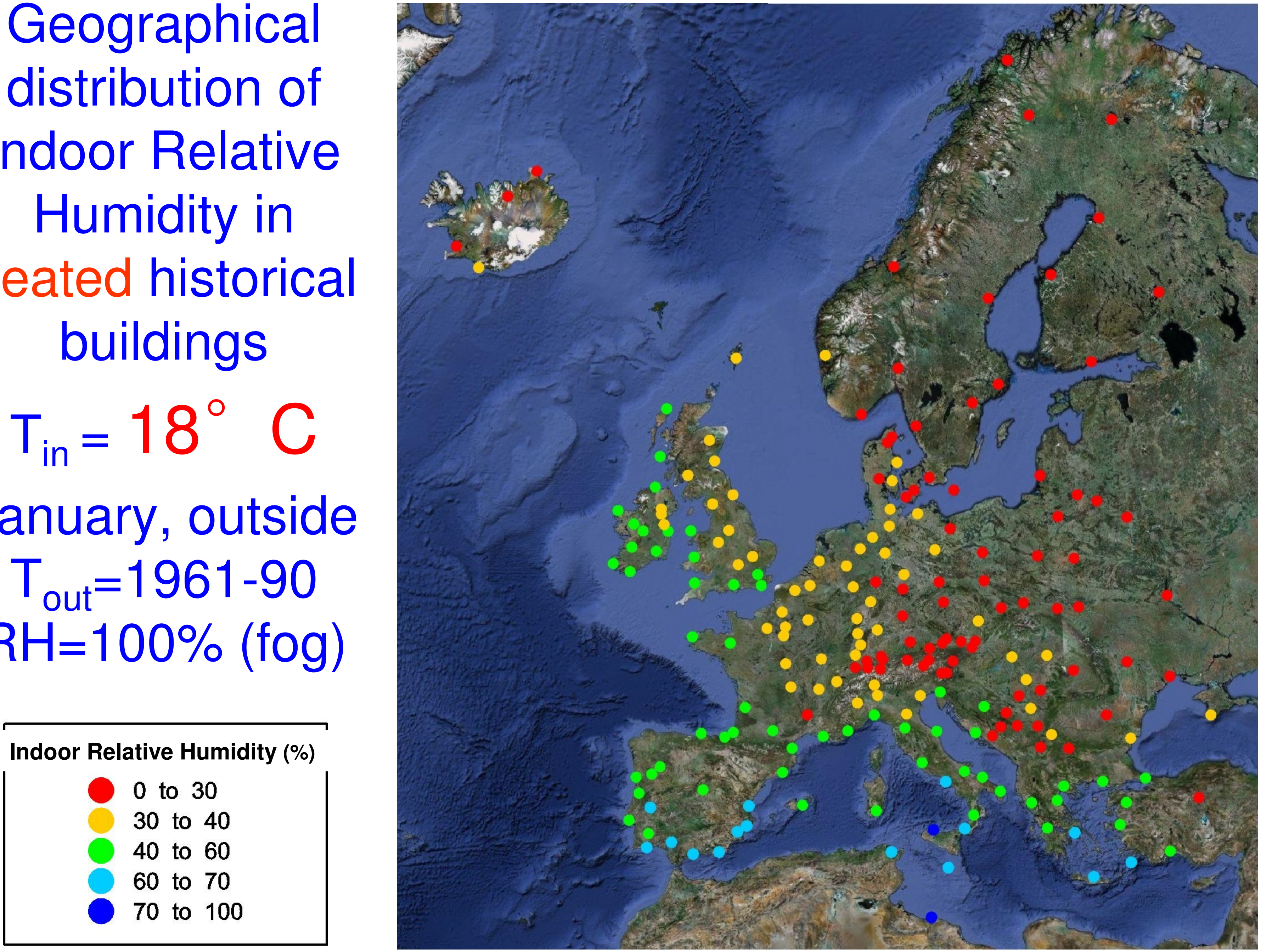
January, outside T_{out}=1961-90 RH=100% (fog)



Geographical distribution of indoor Relative Humidity in heated historical buildings

$T_{in} = 18°\ C$

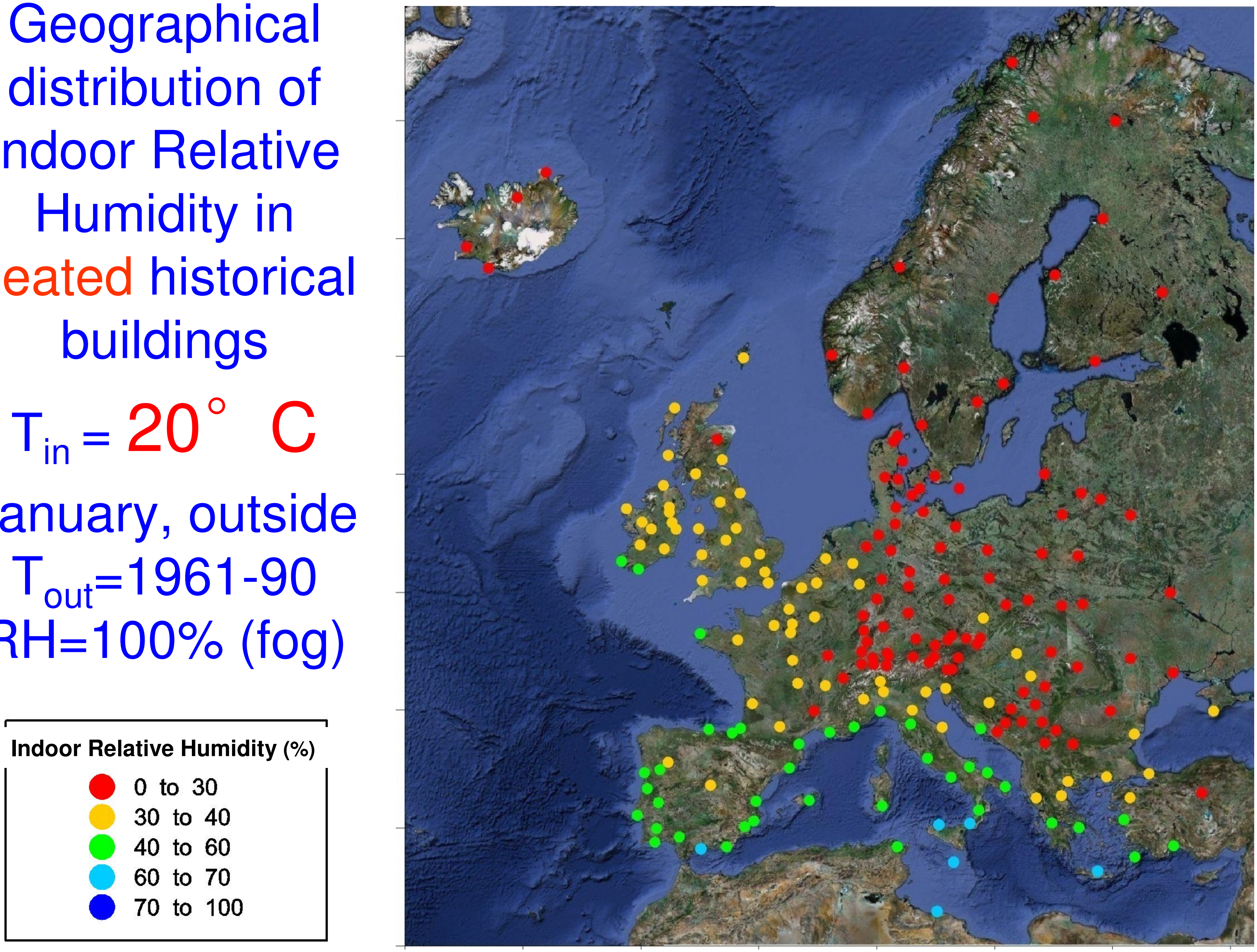
January, outside T_{out}=1961-90 RH=100% (fog)



Geographical distribution of indoor Relative Humidity in heated historical buildings

T_{in} = 20° C

January, outside T_{out}=1961-90 RH=100% (fog)



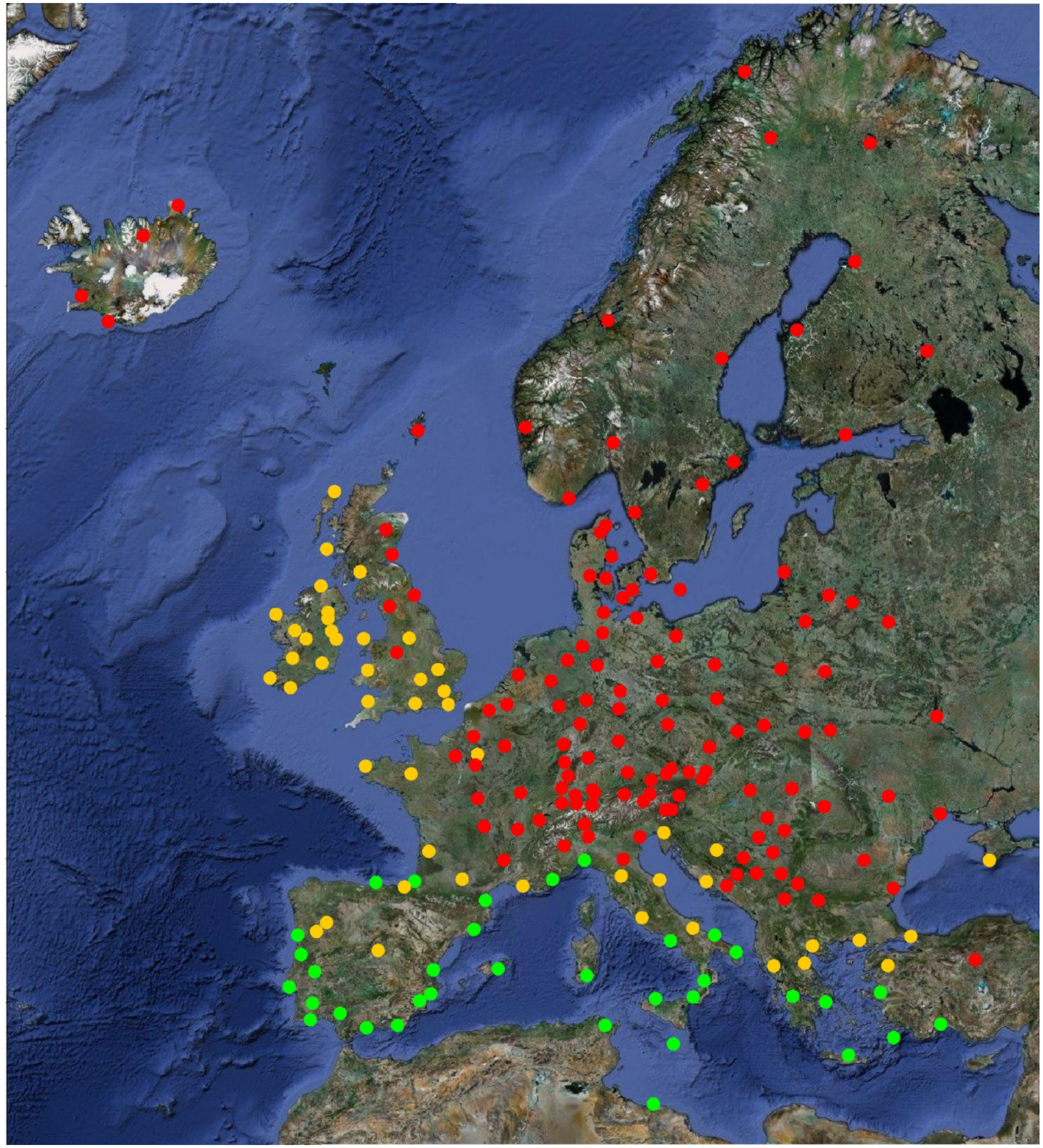
Geographical distribution of indoor Relative Humidity in heated historical buildings

T_{in} = 22° C

January, outside T_{out}=1961-90 RH=100% (fog)

Indoor Relative Humidity (%)

- 0 to 30
- 30 to 40
- 40 to 60
- 60 to 70
- 70 to 100



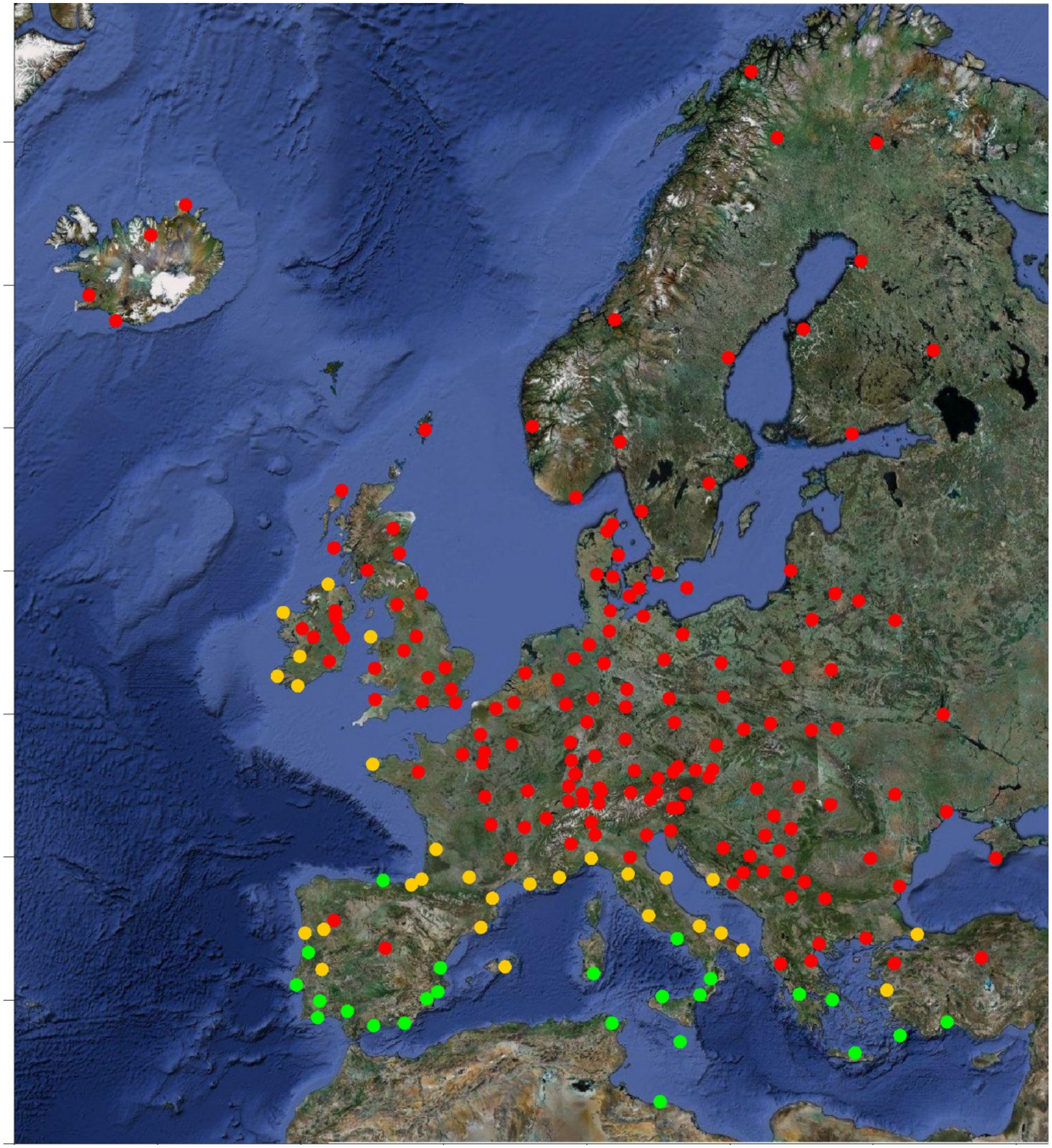
Geographical distribution of indoor Relative Humidity in heated historical buildings

T_{in} = 24° C

January, outside T_{out}=1961-90 RH=100% (fog)

Indoor Relative Humidity (%)

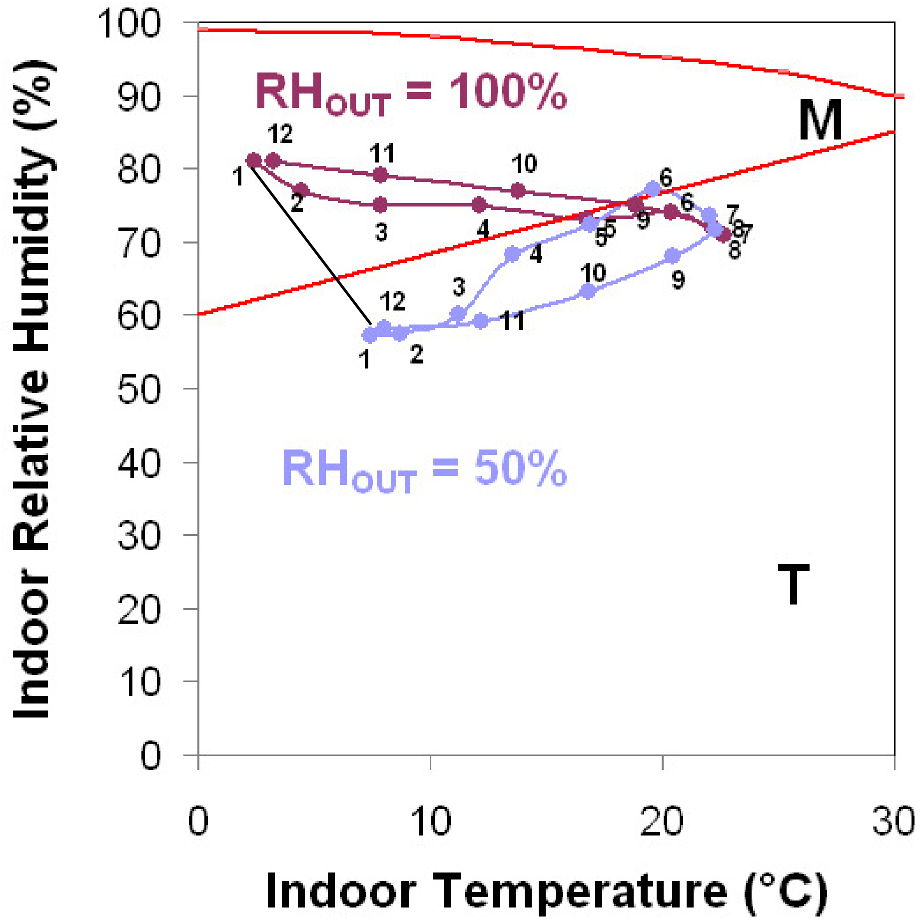
- 0 to 30
- 30 to 40
- 40 to 60
- 60 to 70
- 70 to 100



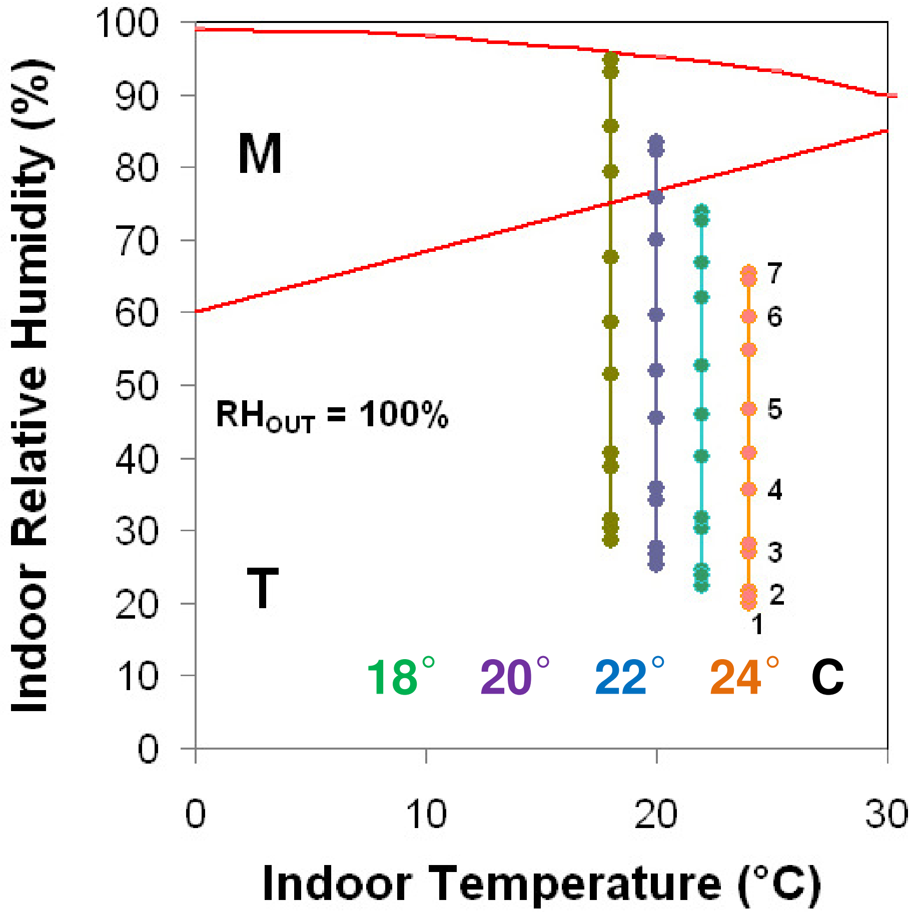
Thenardite-Mirabilite diagram for a historical building in Venice

Damage occurs when a red line is crossed

Unheated Historical Building



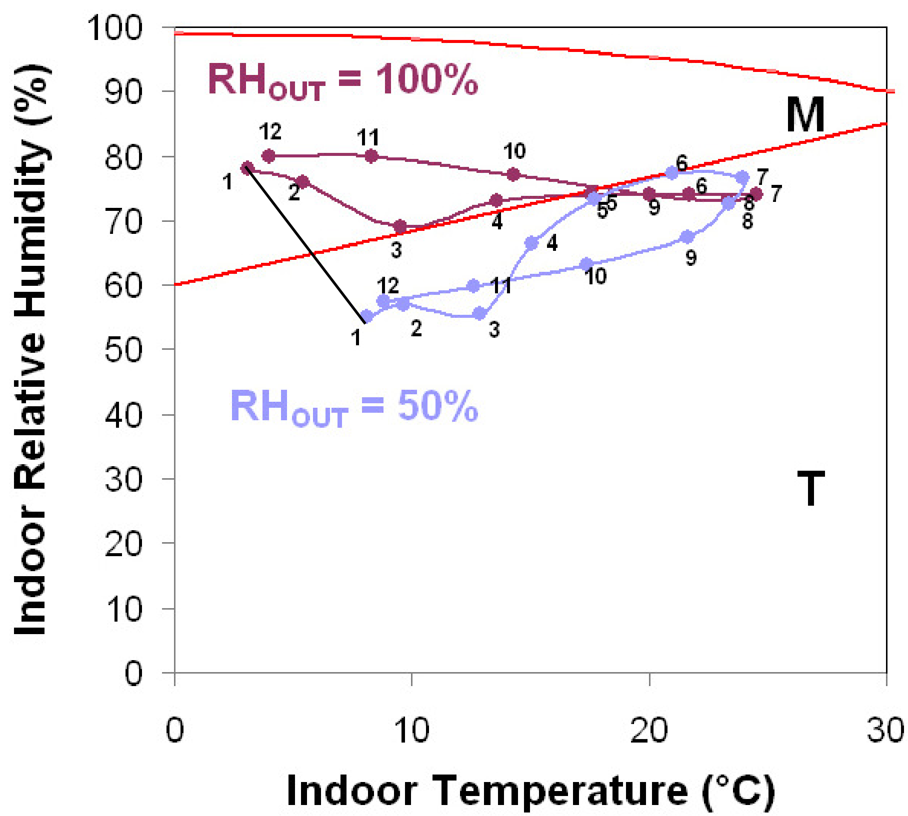
Heated Building



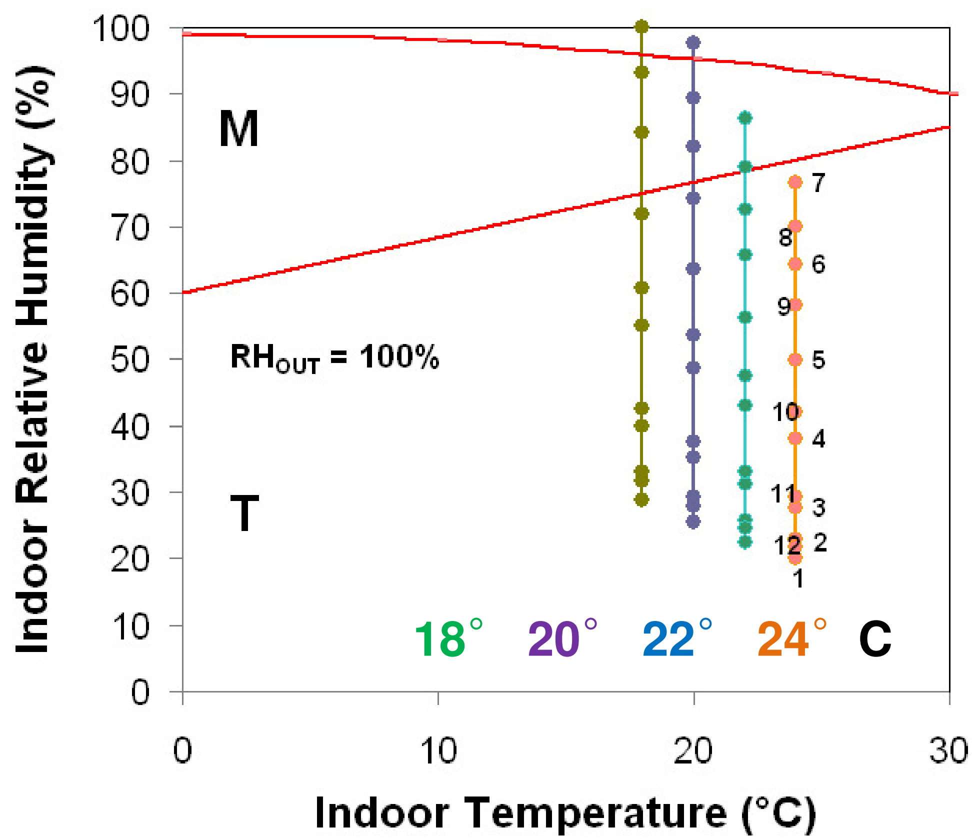
Thenardite-Mirabilite diagram for a historical building in Milan

Damage occurs when a red line is crossed

Unheated Historical Building



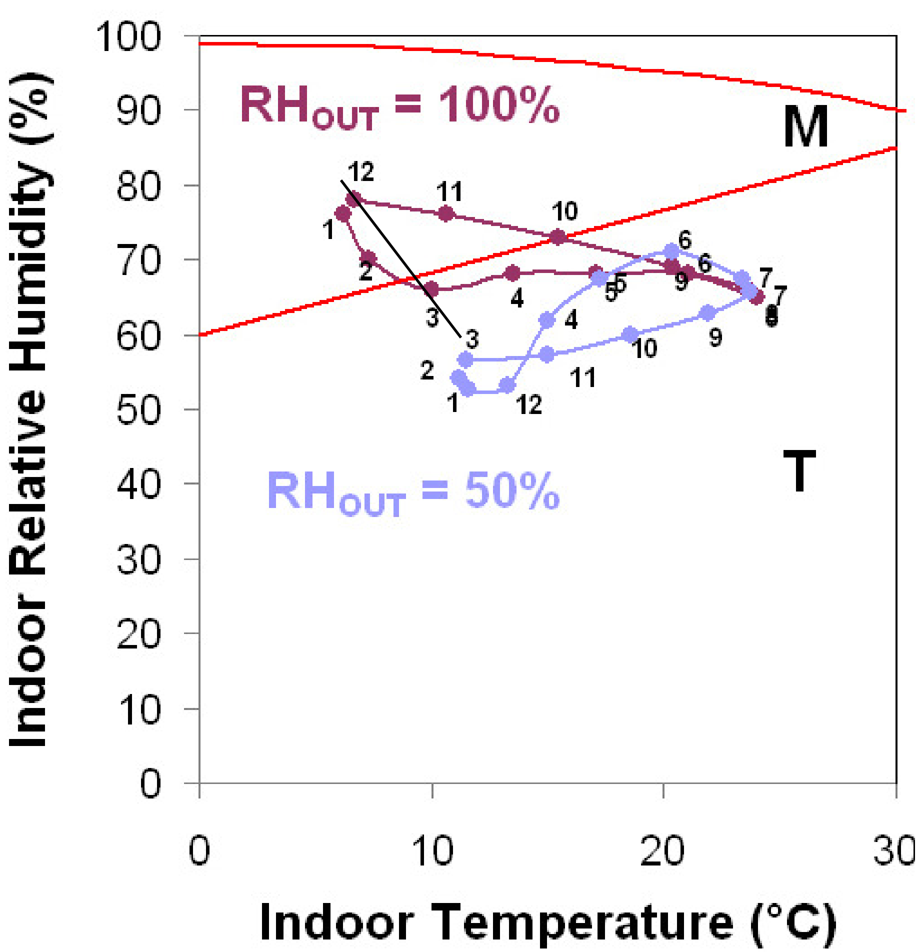
Heated Building



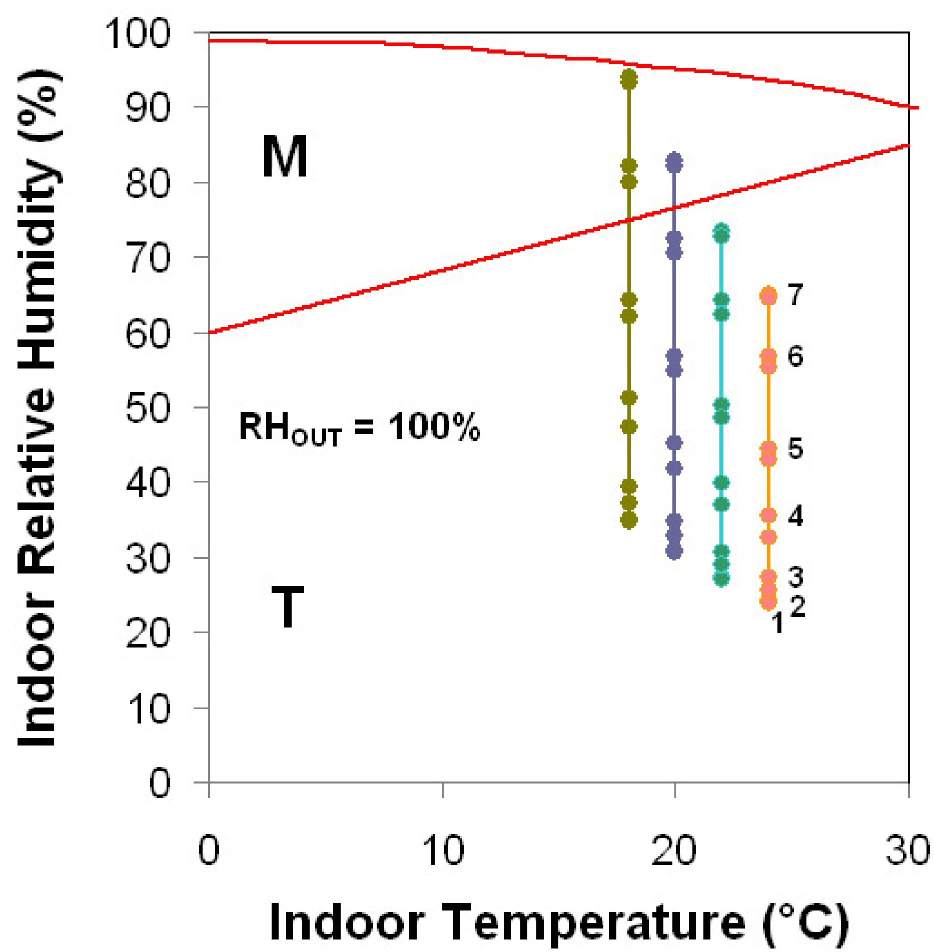
Thenardite-Mirabilite diagram for a historical building in Florence

Damage occurs when a red line is crossed

Unheated Historical Building



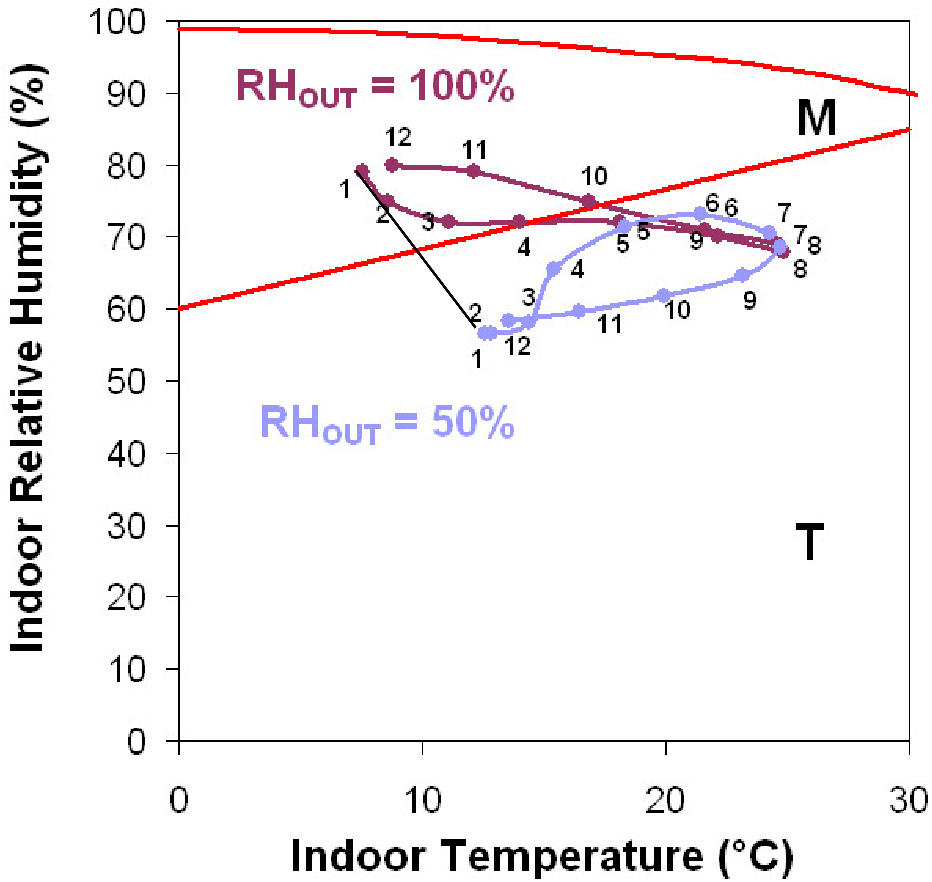
Heated Building



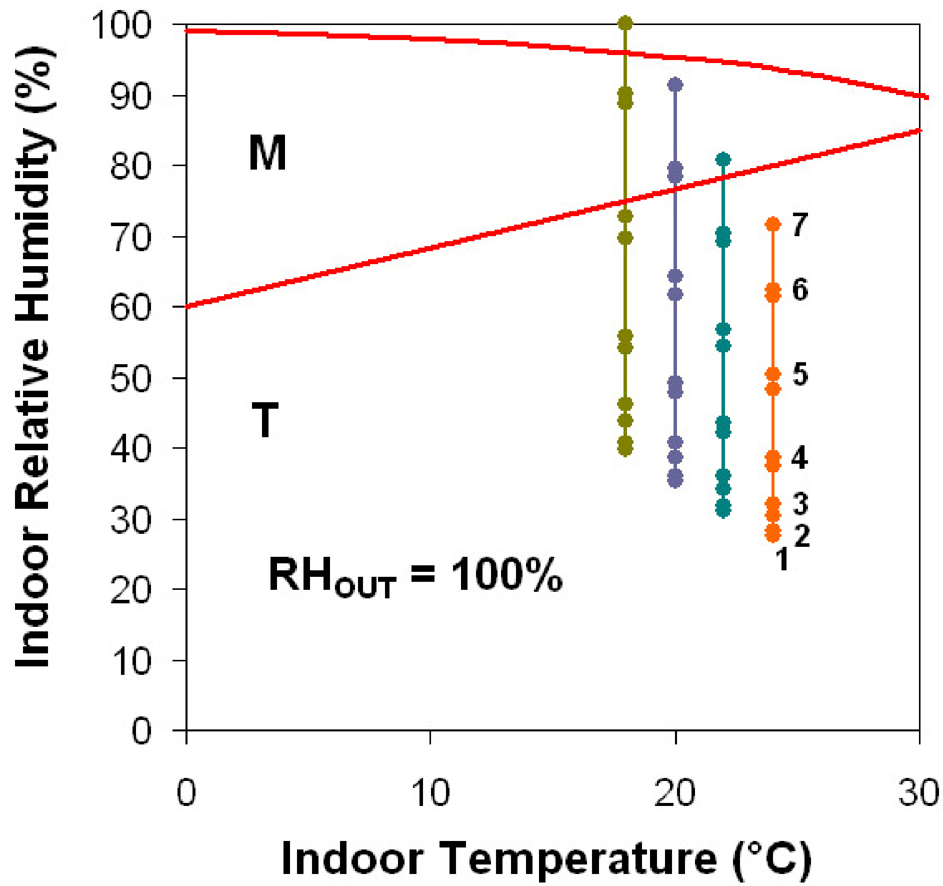
Thenardite-Mirabilite diagram for a historical building in Rome

Damage occurs when a red line is crossed

Unheated Historical Building



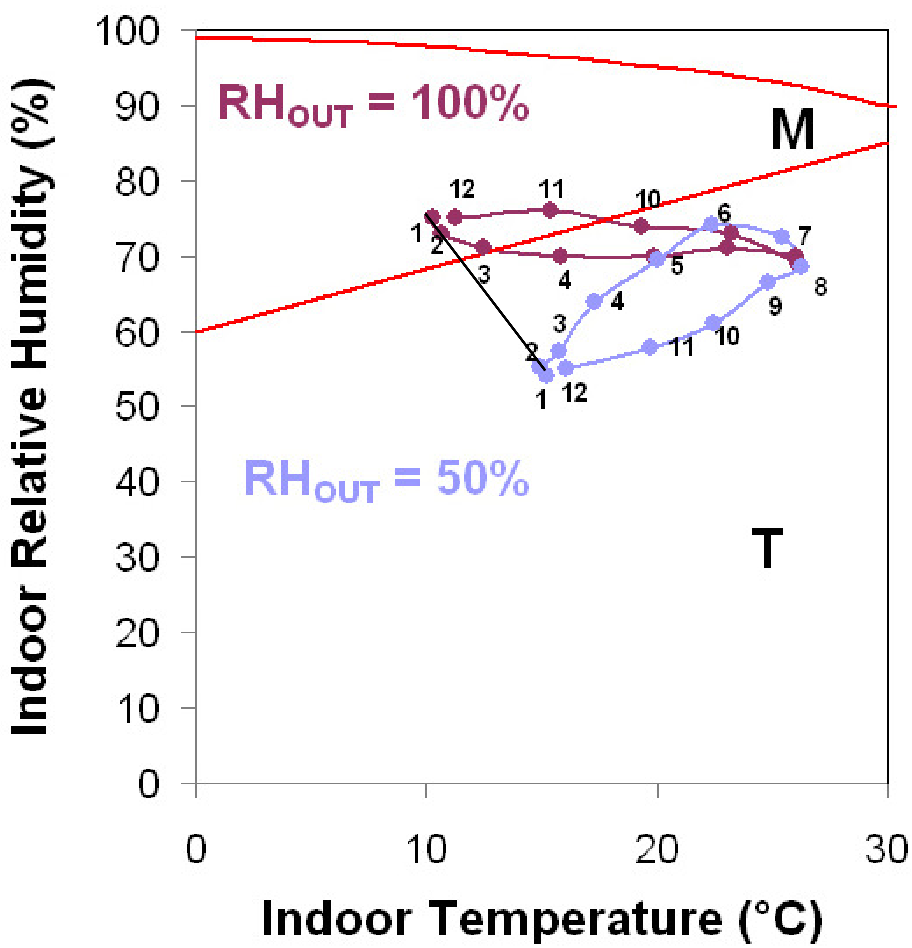
Heated Building



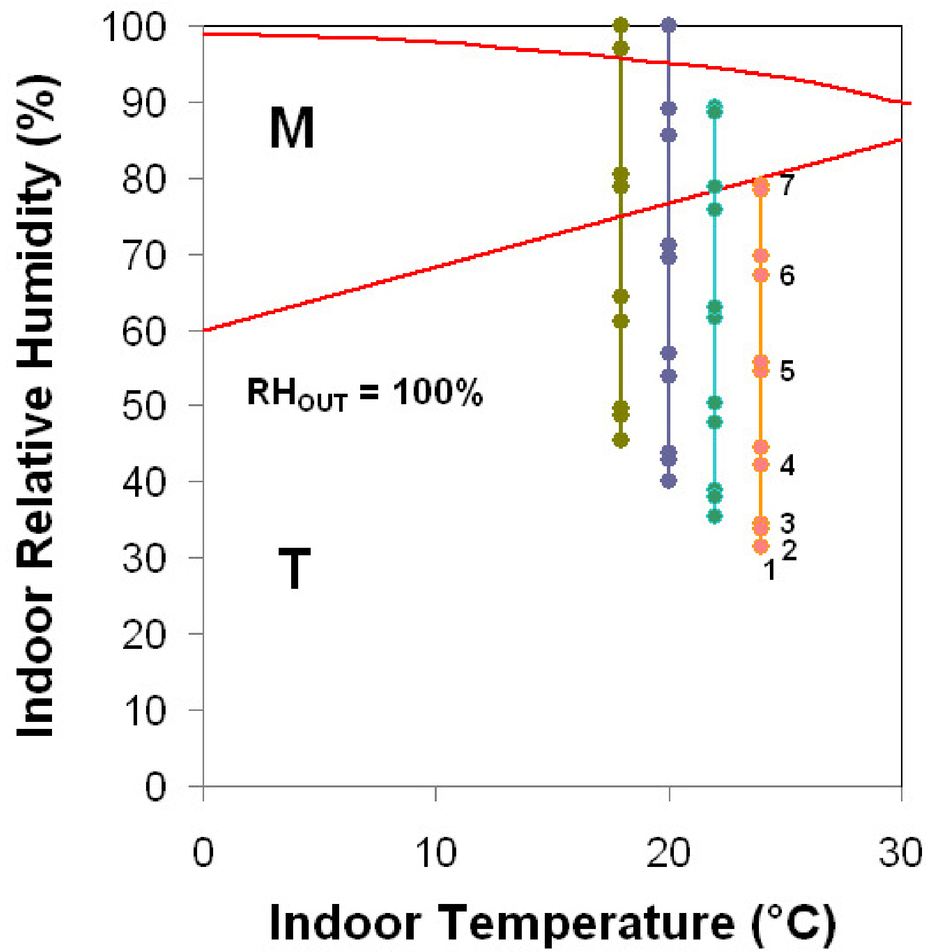
Thenardite-Mirabilite diagram for a historical building in Naples

Damage occurs when a red line is crossed

Unheated Historical Building

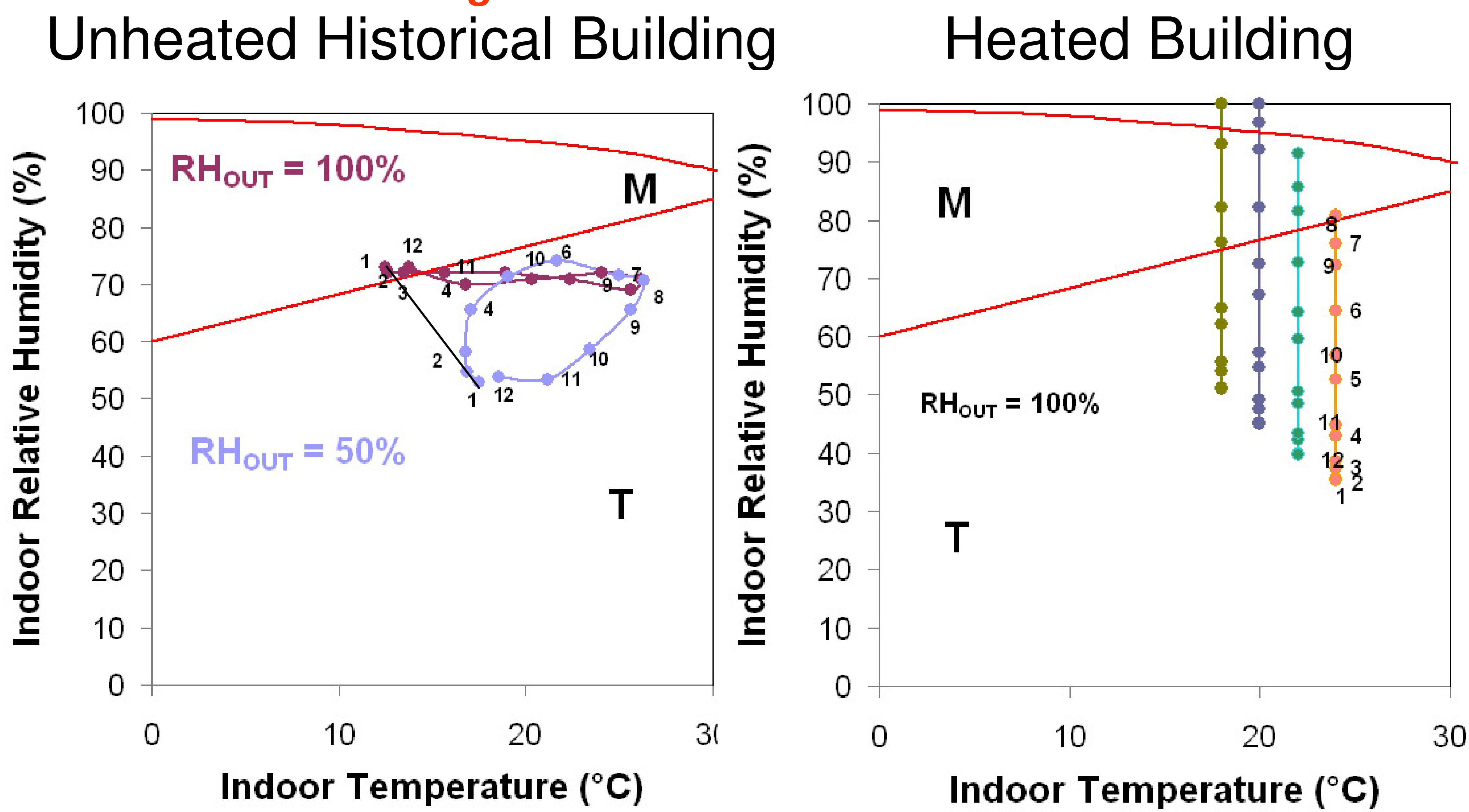


Heated Building



Thenardite-Mirabilite diagram for a historical building in Palermo

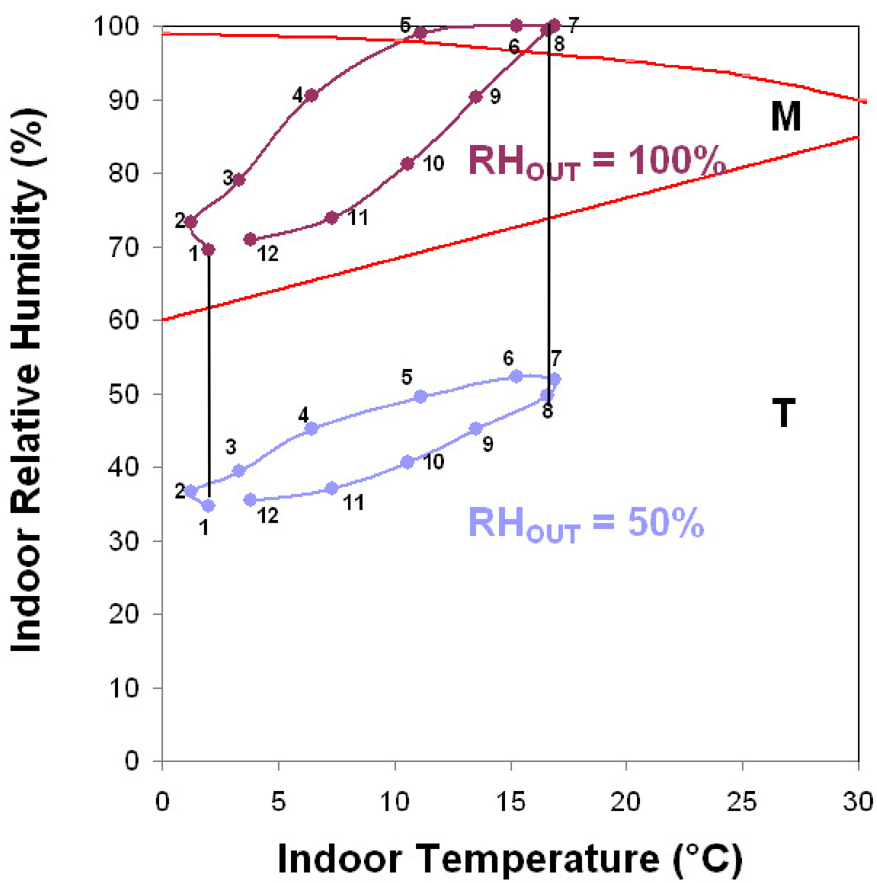
Damage occurs when a red line is crossed



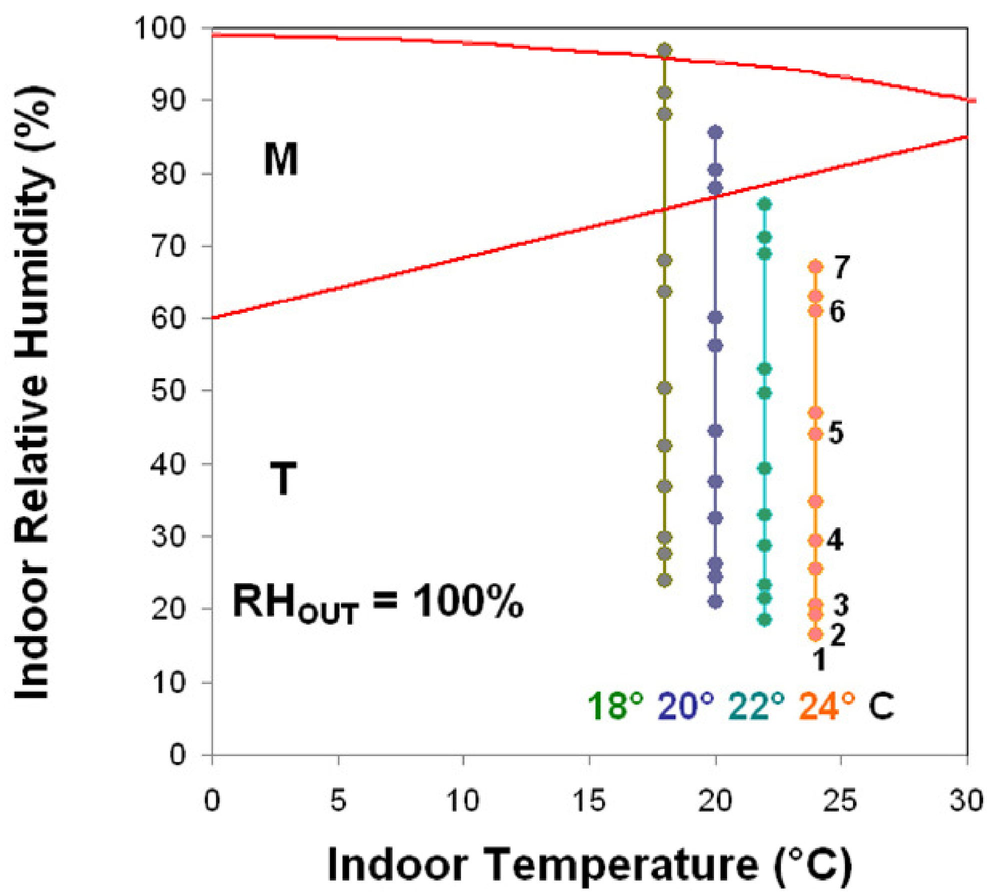
Thenardite-Mirabilite diagram for a historical building in Stockholm

Damage occurs when a red line is crossed

Unheated Historical Building

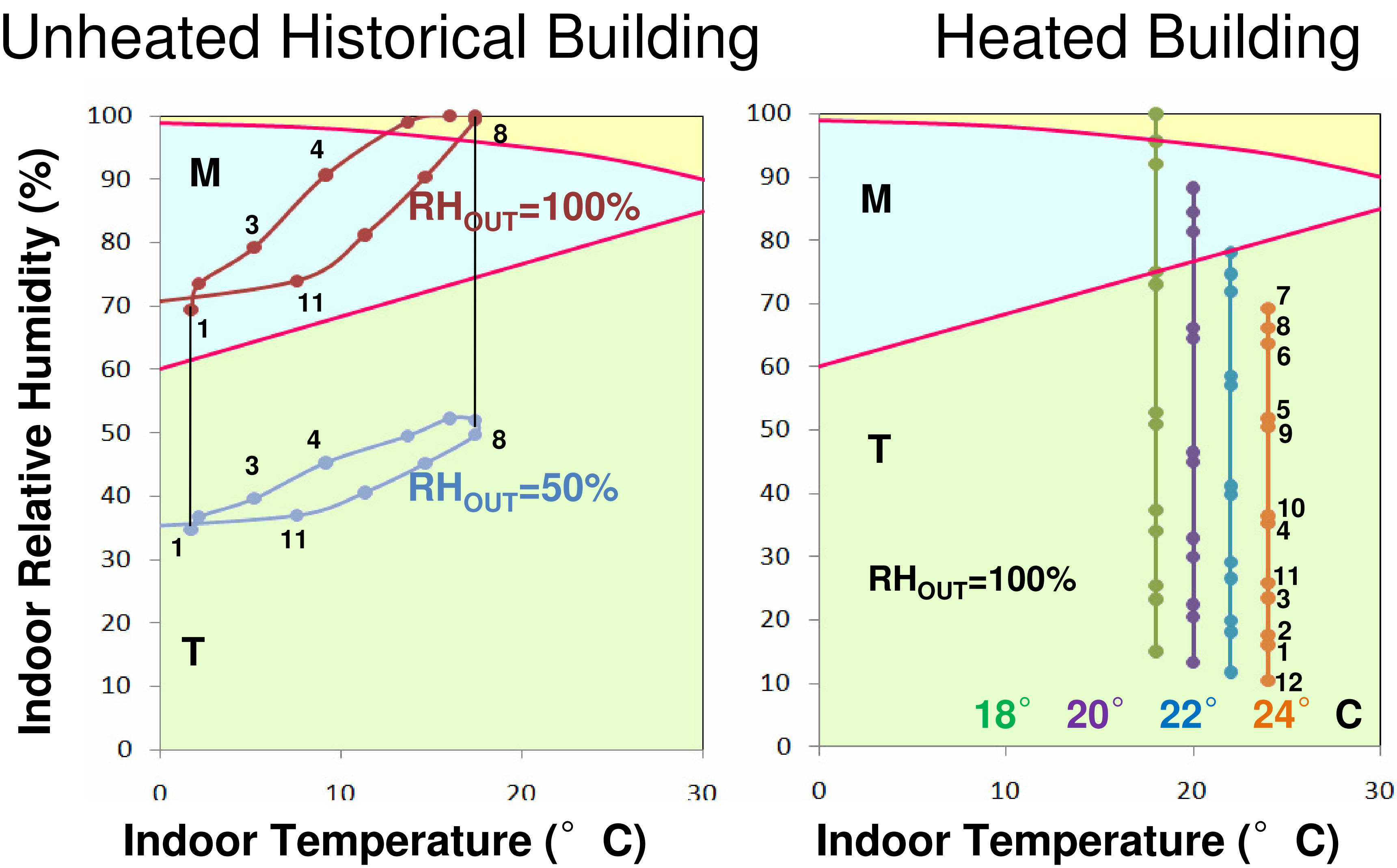


Heated Building



Thenardite-Mirabilite diagram for a historical building in Warsaw

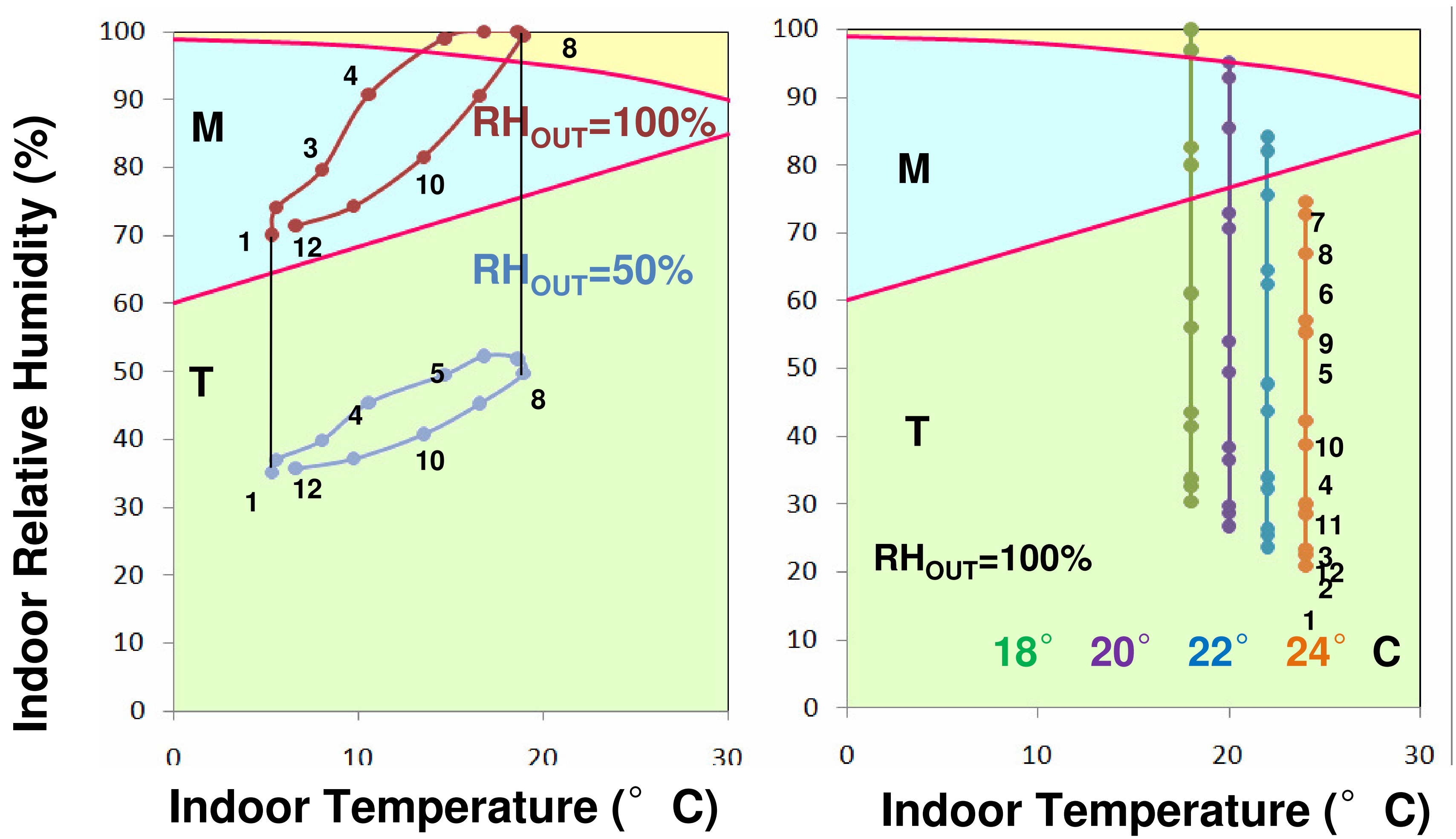
Damage occurs when a red line is crossed



Thenardite-Mirabilite diagram for a historical building in Berlin

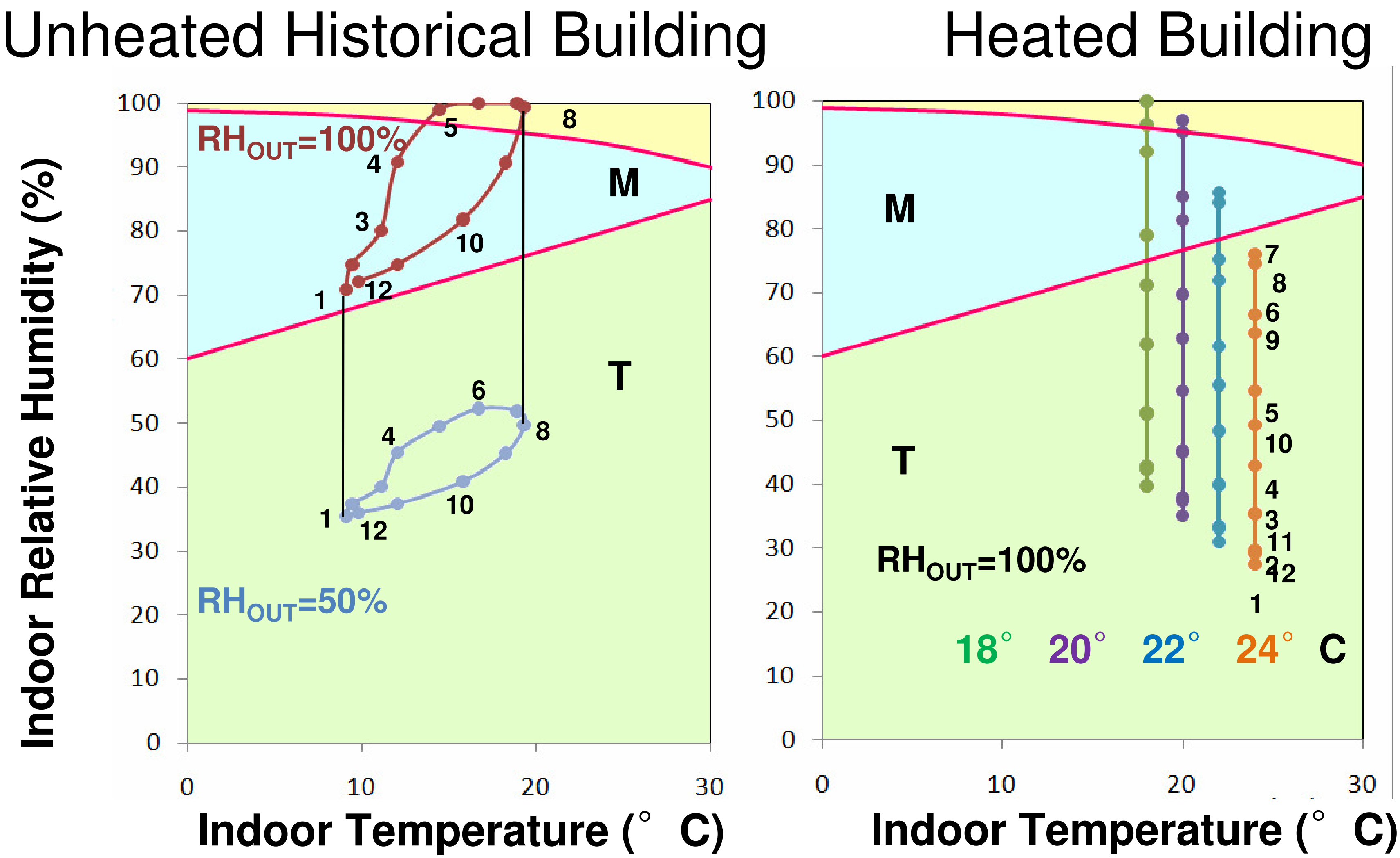
Damage occurs when a red line is crossed

Unheated Historical Building | Heated Building



Thenardite-Mirabilite diagram for a historical building in Paris

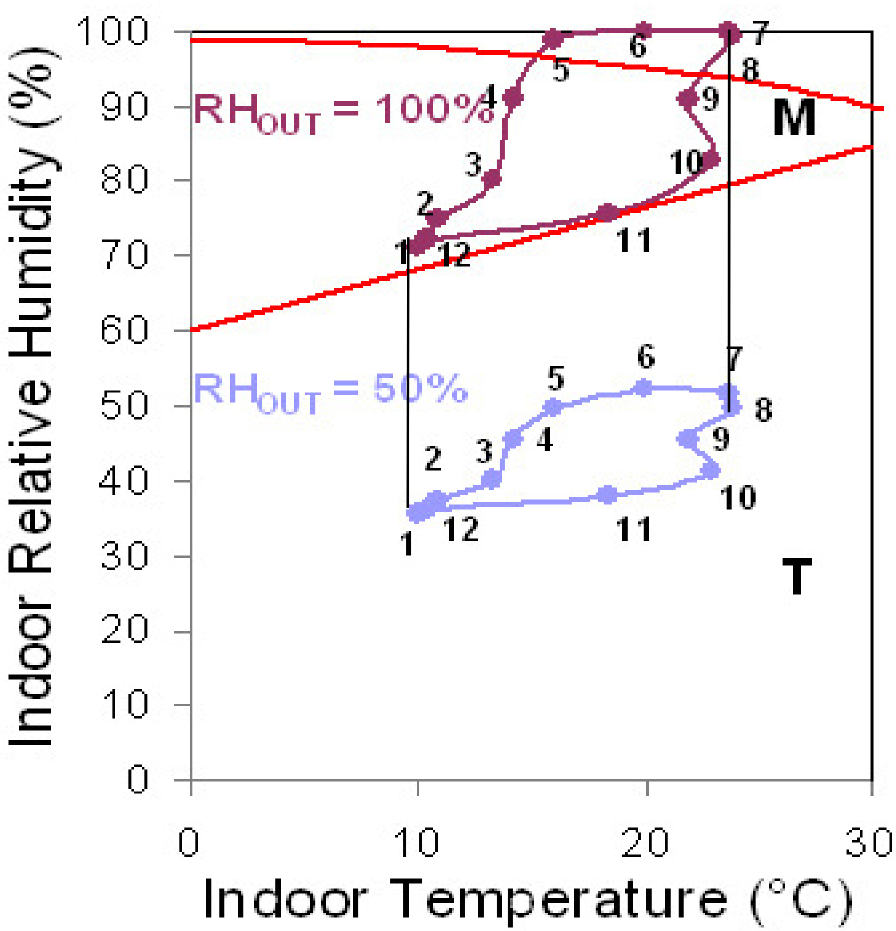
Damage occurs when a red line is crossed



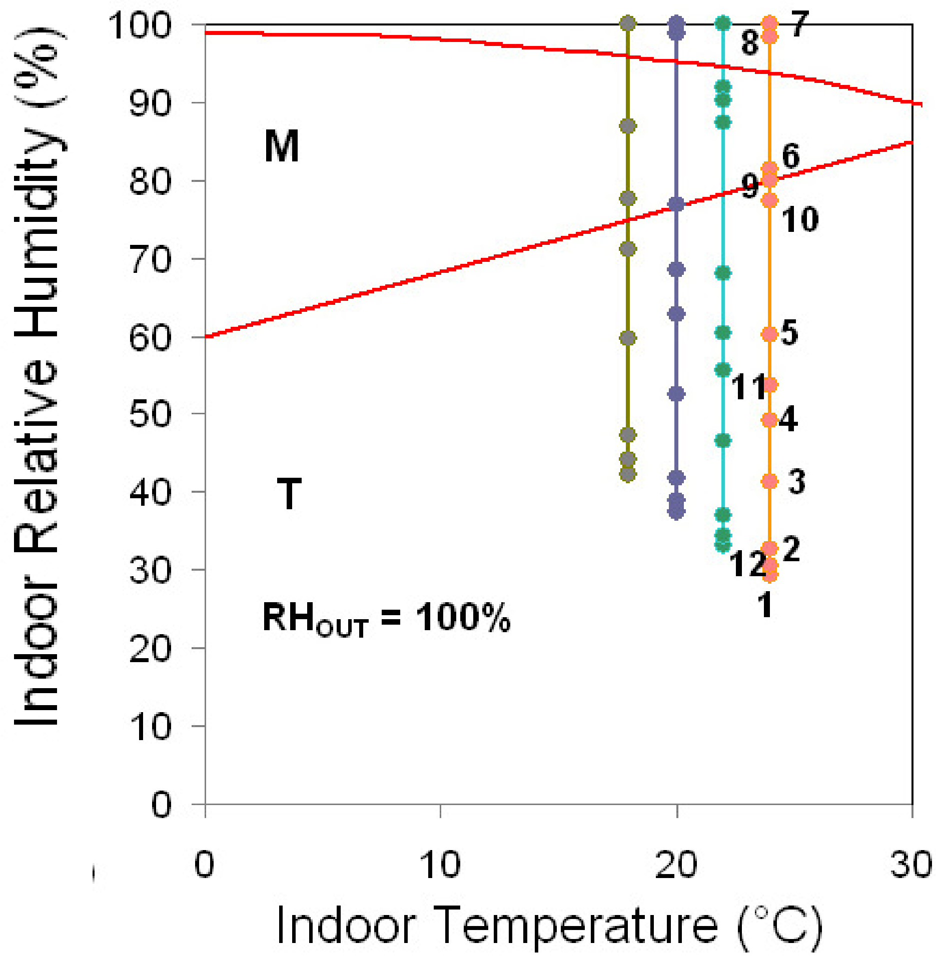
Thenardite-Mirabilite diagram for a historical building in Madrid

Damage occurs when a red line is crossed

Unheated Historical Building

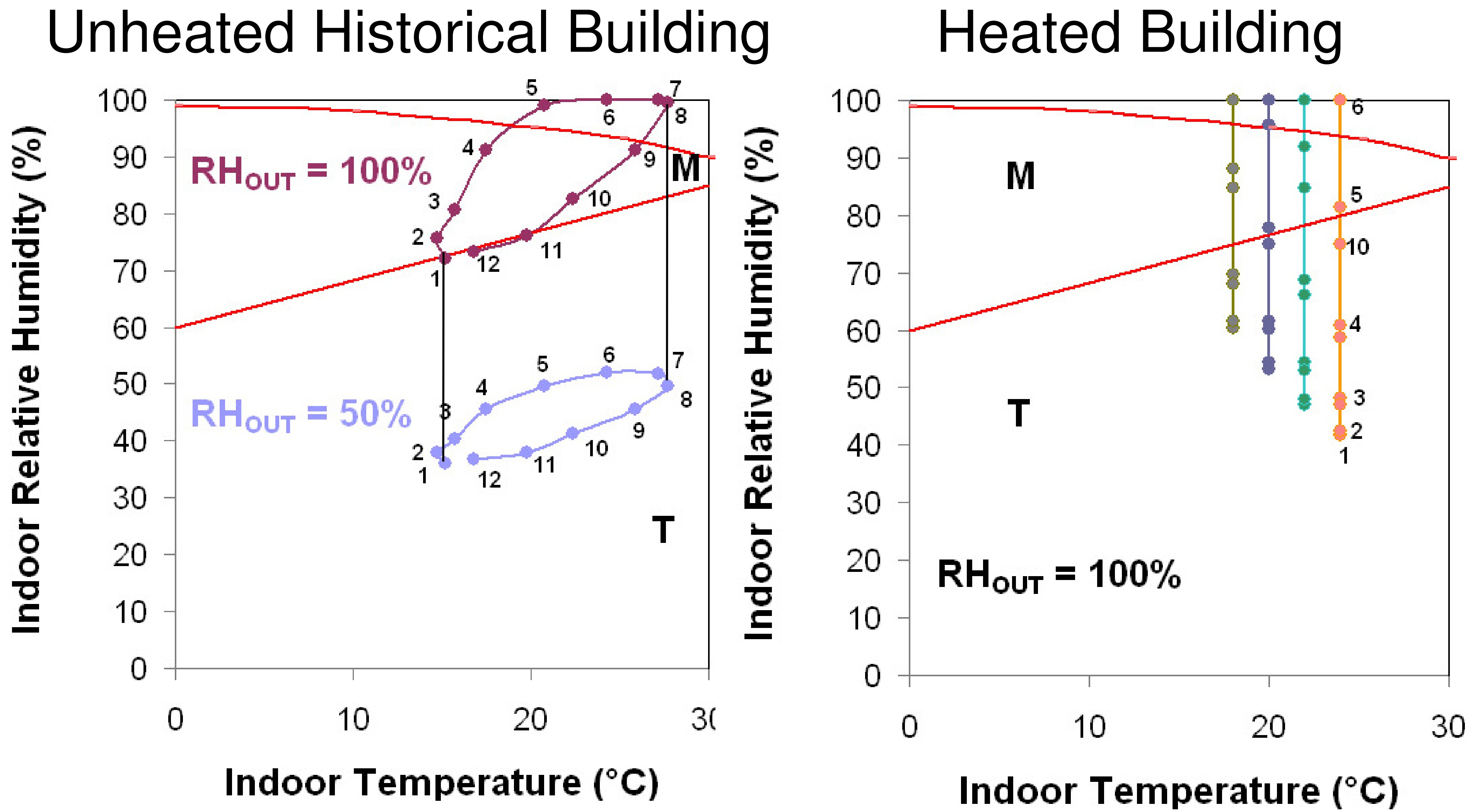


Heated Building



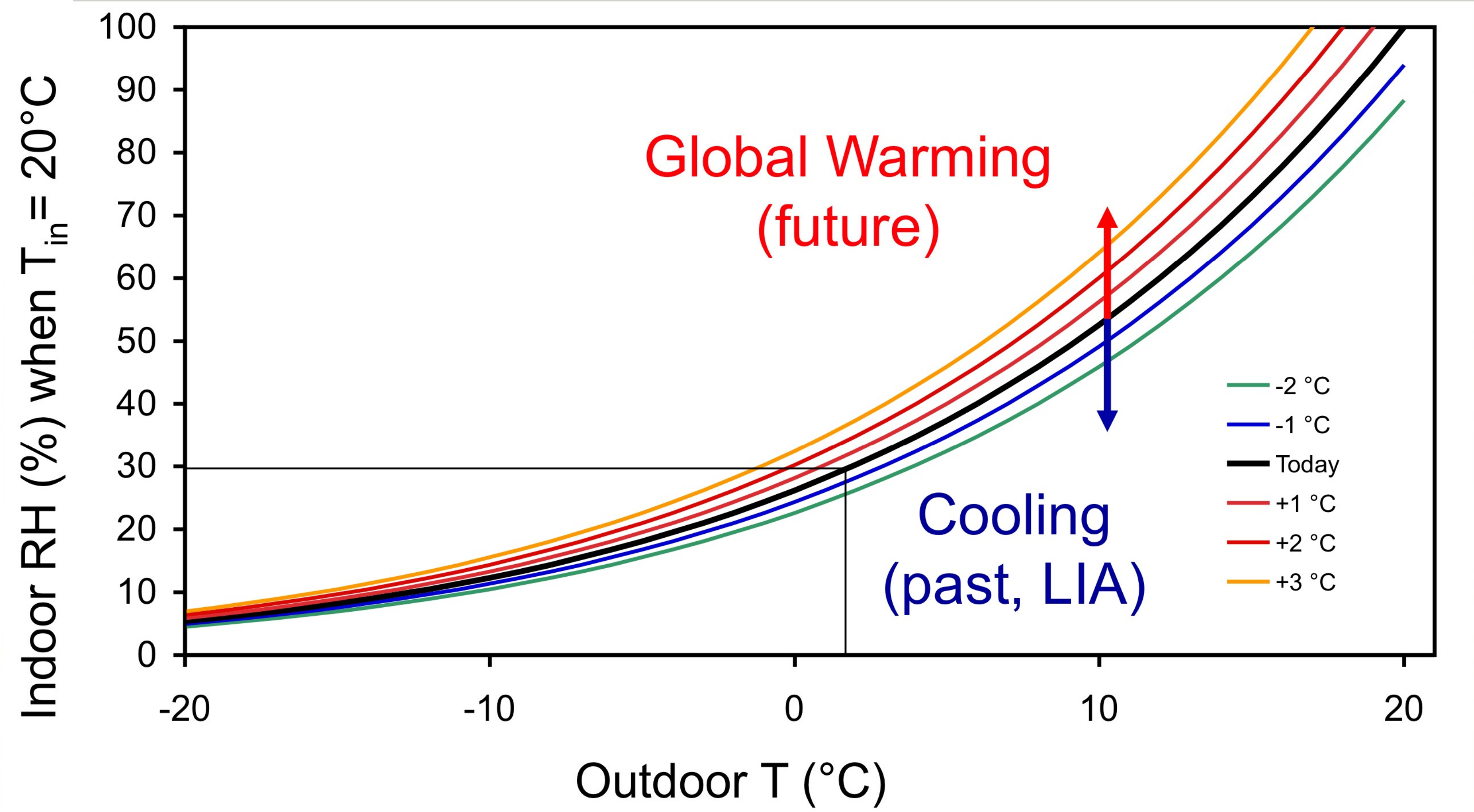
Thenardite-Mirabilite diagram for a historical building in Athens

Damage occurs when a red line is crossed



Global Warming will slightly attenuate the drop of indoor RH for room winter heating (positive factor). On the contrary, external cooling would deepen the RH drop (negative factor).

Indoor heating to 20°C is not sustainable (RH_{in}<30%) when T_{out}<0°C, unless humidifiers are operated. However, humidification is not advisable when a cold wall is present (condensation, mould infestation and soluble salts migration). Lower indoor temperature (i.e. T_{in}<20°C) should be recommended.



Conclusions on the Indoor Climate

Winter heating has dropped RH below the damage threshold for a number of materials for the exceedingly high level of thermal comfort required by people. This is likely to continue for the future and will require changes in the heating strategy (Friendly-Heating) and summer climatization.

Not all consequences of climate changes are negative. With milder winters, air will bring more water vapour, less heating will be necessary, and the indoor RH drop will be reduced.

However, although wood, books, tapestry and other artefacts have suffered for this indoor change, in some cases climatization has been beneficial, e.g. reducing crystallization cycles.

Climate Change has both negative and positive aspects. We should be adequately prepared to afford future challenges, as well as to take benefit from positive aspects.

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SEVENTH FRAMEWORK PROGRAMME

Climate for Culture