ITE
Ίδρυμα Τεχνολογίας & Έρευνας

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE

International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

Preventive impact assessment strategy by monitoring deformation threshold for early risk assessment

Vivi Tornari

vivitor@iesl.forth.gr

***Group IESL**: Eirini Bernikola, Kostas Hatzigiannakis, Michalis Andrianakis and Nota Tsigarida, Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas (GR);*

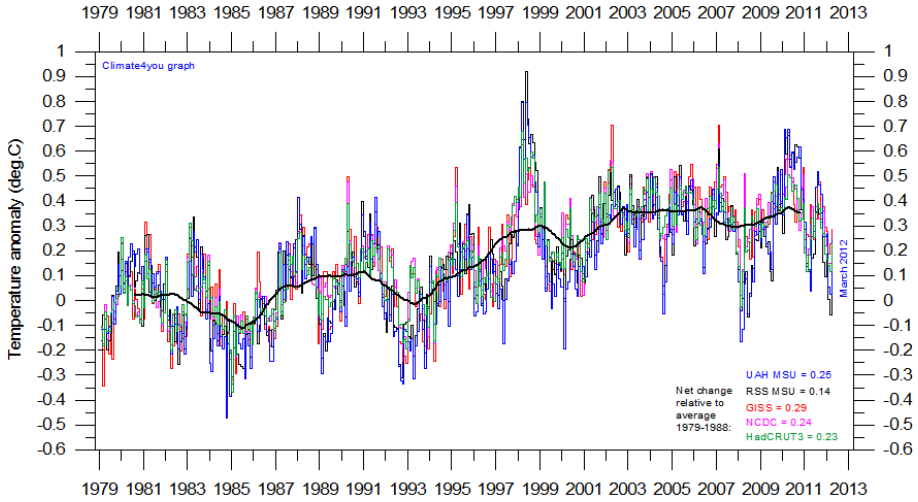
***Coordinator of CfC**: Johanna Leissner, Fraunhofer Institute for Silicate Research (DE)*

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH
Institute of Electronic Structure and Laser

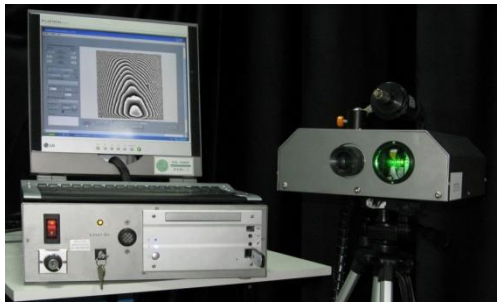
Climate for Culture

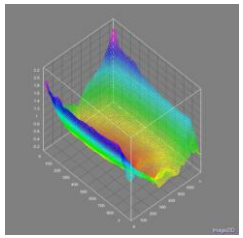
Introduction

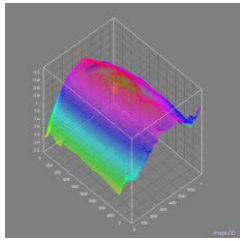


Small and slow -but steady- change within
Safe average change T/RH

Interferometric surface monitoring* via DHSPI system







* "Preventive deformation measurements on cultural heritage materials based on non-contact surface response of model samples", V. Tornari, E. Bernikola, N. Tsigarida, M. Andrianakis, K. Hatzigiannakis, J. Leissner, Studies in Conservation, Volume 60, Issue S1 (August, 2015), pp. S143-S158

"Laser Interference-Based Techniques and Applications in Structural Inspection of Works of Art", V. Tornari, *Analytical and Bioanalytical Chemistry*; **387,** 761-80 (2007).

"Fully non contact holography-based inspection on dimensionally responsive artwork materials". V. Tornari et al., Sensors 2008, 8, DOI 10.3390/sensors (2008)

"Rapid initial dimensional changes in wooden panel paintings due to simulated climate-induced alterations monitored by digital coherent out-of-plane interferometry, E. Bernikola V. Tornari et al., Applied Physics A **95**, pp. 387-399 (2009).

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

EXPERIMENTAL CONCEPT

- **Environmental changes have an impact on the structure** of materials, **slowly but steadily** the structural mechanical status of each body as expressed in **its elasticity towards changes is affected**

- Hygroscopic **materials undergo through time** successfully **changes in response to relative humidity changes** (RH), wherein the safe limits of RH is depending on the type of material, construction and age

- Materials and structures are **in sometime altered and then "broken"**

- The moment the material can not successfully tolerate the changes of RH are the moments when **the physical-mechanical parameters change.**

- **Determination of these moments can predict alteration at an earlier stage to warn for increase risks of damage, before irreversible damage**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

EXPERIMENTAL PROCEDURE

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

1. Selecting an environmental zone - e.g. zone 4, zone 1
2. Selection of extreme values of RH-time, season, average daily
3. Selection of specimens that are susceptible to changes in RH

1. Simulation of selected RH values in an airtight chamber using salts
2. Sample preparation and placement, free on scales
3. Surface deformation measurement in real time for each RH cycle
4. Relative displacement (RD) (in μm) and rate of displacement (RoD) (μm/h)

1. Repeat cycles-steps 5 and 6 -through time
2. Calculation of Volumetric Deformation ε
3. Correlation ε to RoD
4. Find deformation limits and RoD over which irreversible damage is caused

Our goal is to correlate volumetric deformation with RoD and to find the limits of deformation over which irreversible damage is caused.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Data from Historical Sites examples

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE

International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

Dubrovnik Cathedral crypt-CR

Brezise castle -SL

Sensors
DHSPI, 3DM

Eisodia Theotokou

Agia Triada - Archanes

Agios Fanourios
Valsamonero GR

Staunton Harold Church
UK

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH
Institute of Electronic Structure and Laser

Climate for Culture

Terms and conjectures

- Interferometry detects microscopic optical-path changes L-ΔL of surfaces (L_x,L_Y L^2), with **d** being the **initial** surface position $\mathbf{t_0}$, reference surface distance from the surface to the detector;
- when **d > Nλ/2 = D** (N integer) interferometry detects displacement D as multiples N of λ/2 (microns)
- If the surface changes occur **as continuous process of function of time t**, displacement D is not static event and an **infinite transition of relative D in surface position** may be captured.
- **Relative Displacement** (RD) **is the change of the surface of the sample** at any time $\mathbf{t=t_v}$ in comparison **to the reference state** at **t=0** (differentiation)
- **Rate of Displacement** (RoD) - Relative **Displacement** reveals how quick the sample reacts to any load that is applied **as a function of time**
- **Deformation** is the **change of volume** of sample **to original volume** of the sample

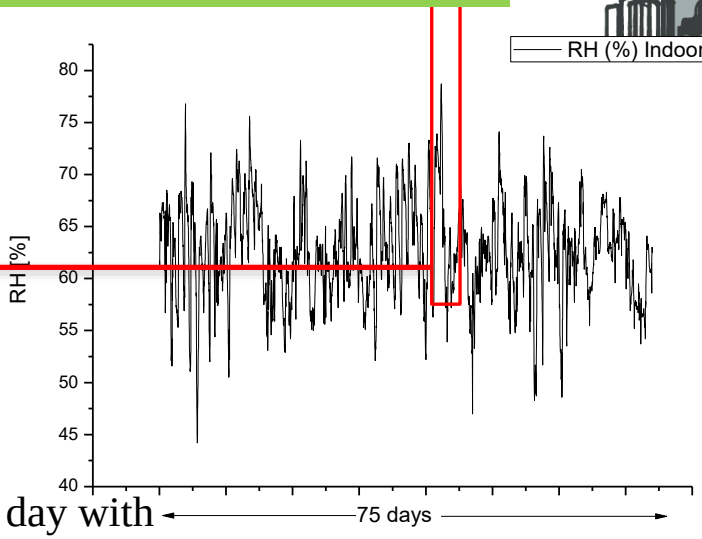
$$\frac{\Delta V}{V} = \frac{(d_{i+1} - d_i) \times (L^2)}{d_0 \times (L^2)} = \frac{d_{i+1} - d_i}{d_0} = \frac{RD_{i+1} - RD_i}{d_0} = \frac{\Delta d}{d}$$

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

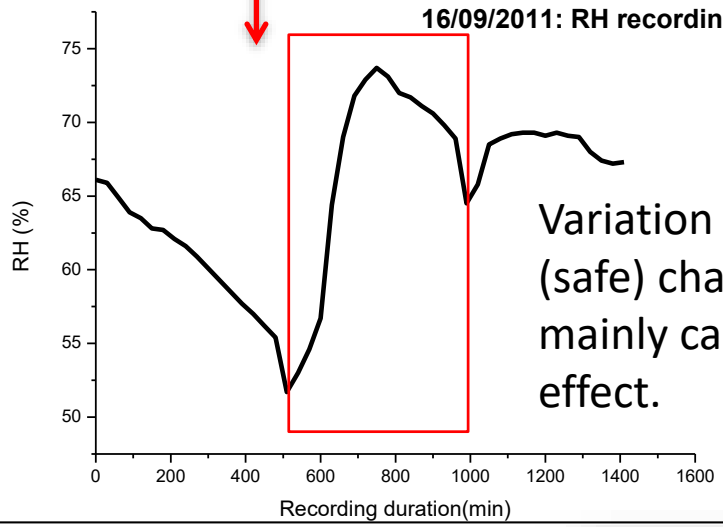
Actual data – Historical site Zone 4 Dominican Monastery of St. Peter, Heraklion,



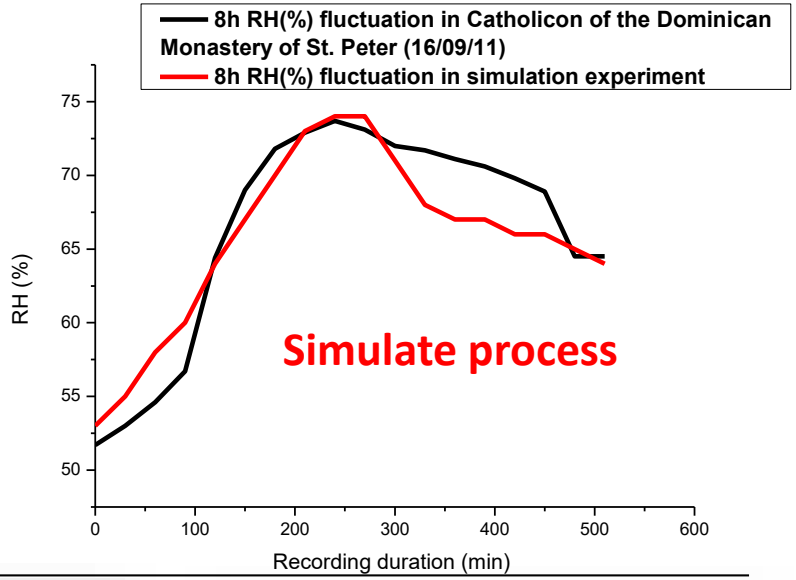
RH Fluctuation values

- **INCREASE** of 22% (RH) in 4h (average **5%/h**)
- **decrease** of 9.2% (RH) in 4h (average **2.3 %/h**)

Selection of day with max RH fluctuation



Variation with mild (safe) changes to mainly cause swelling effect.



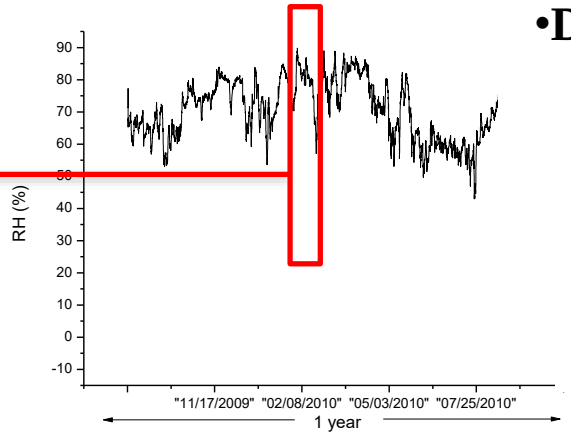
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Actual data - historical site ZONE 1
Skokloster castle, Sweden

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece



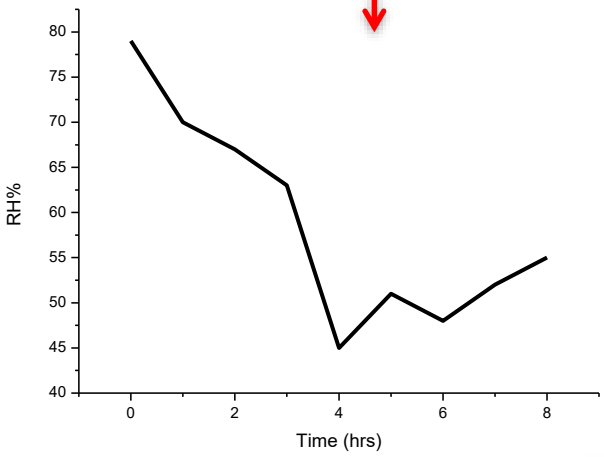
Selection of day with max RH fluctuation

RH Fluctuation values

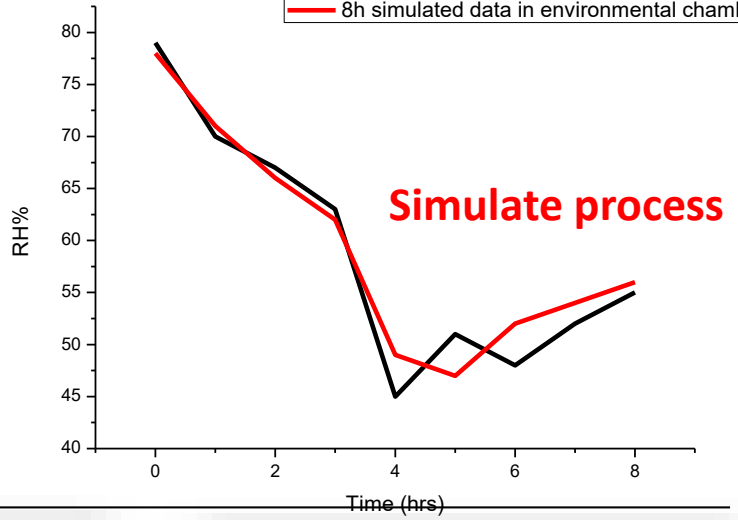
- **DECREASE** of 34% (RH) in 4h (average **8 %/h**)
- **increase** of 10% (RH) in 4h (average **2.5%/h**)

Simulation of

- **decrease of 34% (RH) in 4h**
- **raise of 10% (RH) in 4h**



Variation with strong (safe) changes to mainly cause shrinking effect.



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

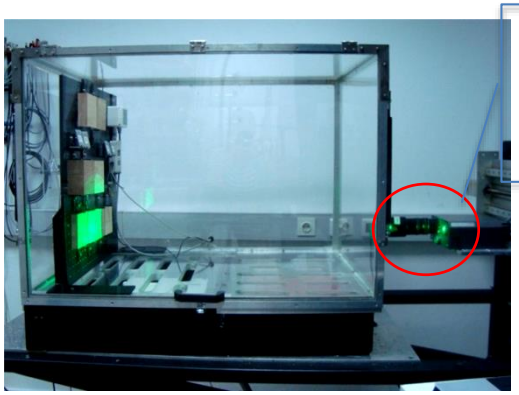
Climate for Culture

Materials and methods
Laboratory Experimental setup

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

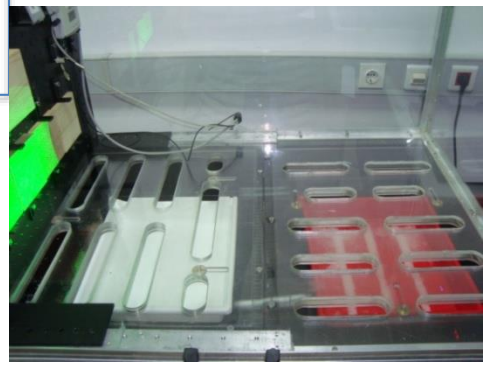
- Automatic remote surface recording /pre-set intervals
- Installation of GS, FWS and Krah & Grote data loggers
- Saturated salt solutions
- Samples: 2 wood densities, 1 fiber orientation,

  3 thicknesses



Climate chamber

DHSPI system – remote real time automatic recording

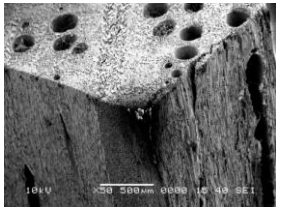


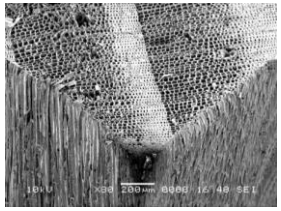
Saturated salt solution built-in cases

FWS installed inside wooden samples

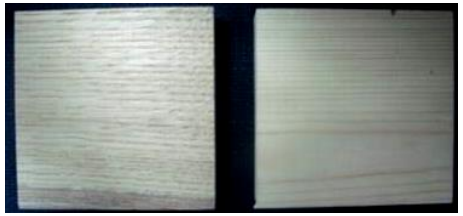
Saturated salts solutions

Sodium Chloride (NaCl)	Potassium sulfate (K_2SO_4)	Magnesium nitrate-Sodium chloride ($Mg(NO_3)_2$ – NaCl)	Magnesium nitrate ($Mg(NO_3)_2$)	Silica gel

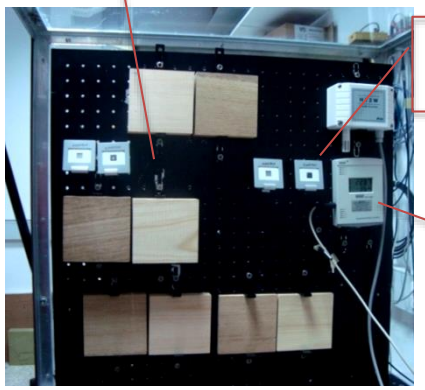




(a) Hardwood-Oak (b) Softwood-Pine



(a) Oak radial ,(b) Pine radial



Glass sensors

Krah& Grote data logger

Perforated holder and wooden samples

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

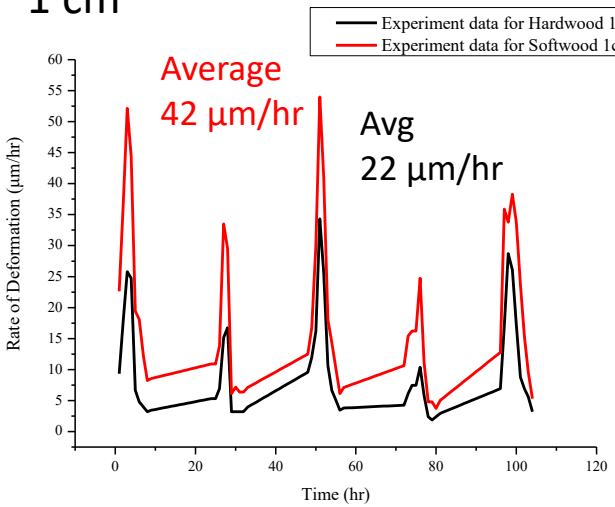
FORTH Institute of Electronic Structure and Laser

Climate for Culture

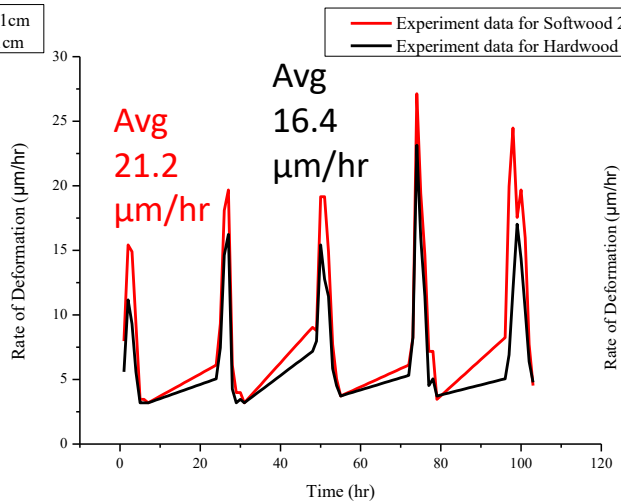
Surface measurements of RoD - RH increase- 24h cycle , zone 4

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

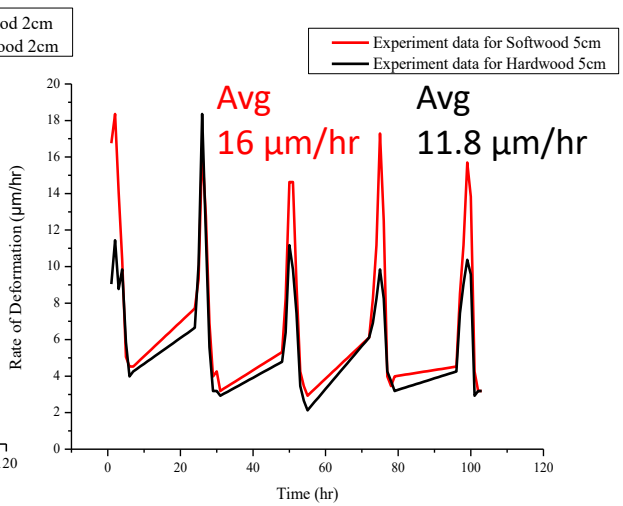
1 cm



2 cm



5 cm



In **red** line softwood from left to right 1, 2, 5 cm: monitoring for
In **black** line hardwood from left to right 1, 2, 5 cm

- Softwood follow RH at higher rate
- 1cm thickness follow RH changes at higher rate
- **six different intensity cases of deformation characteristics are revealed corresponding to typical risk indicators**
- linear interpolation (on 16 h soft drying out process)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

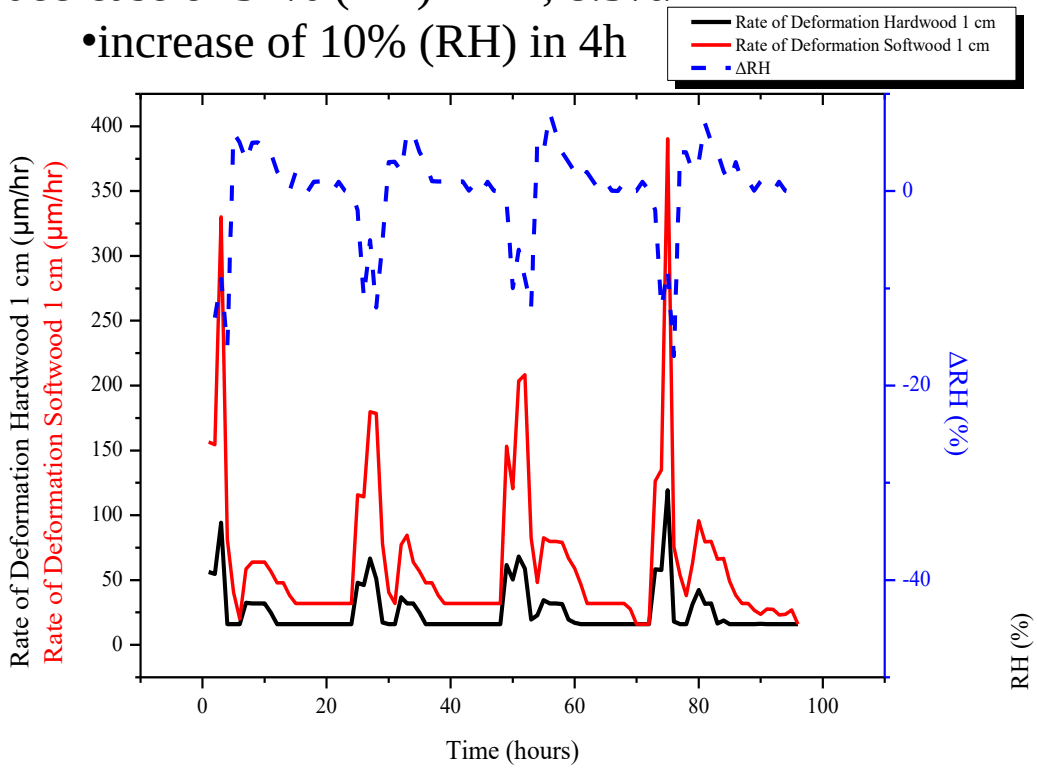
FORTH Institute of Electronic Structure and Laser

Climate for Culture

Surface Measurements of RoD, RH decrease– 24h cycle – 24h data for 4 days, zone 1, MC, 1 cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

- decrease of 34% (RH) in 4h, 8.5%/hr
- increase of 10% (RH) in 4h

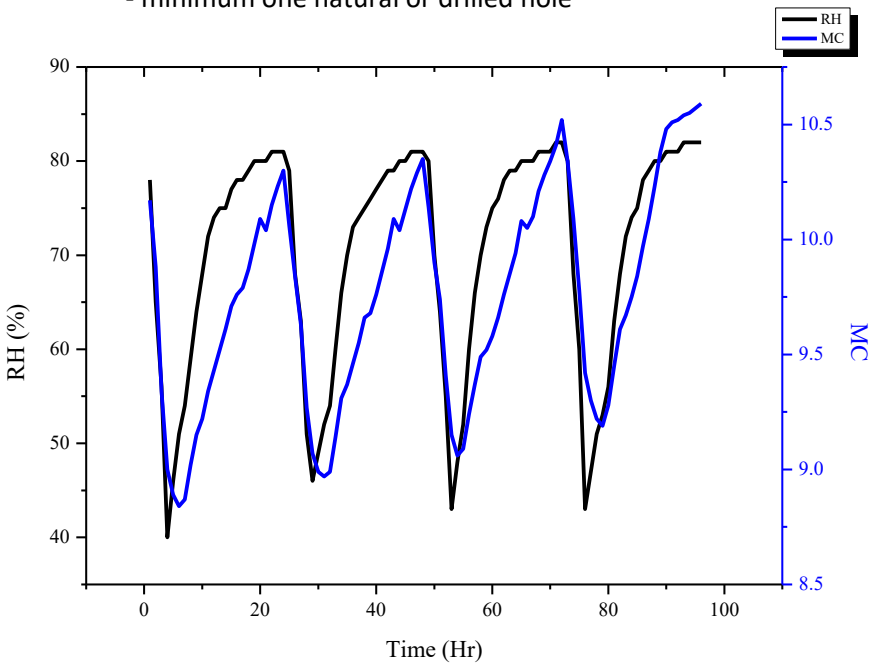


MC calculation from wood

$$Y_{MC} = \frac{M_x - M_0}{M_0} \times 100\%$$

Y = Moisture (%)
Mx = initial weight (g)
M0 = final weight (dried-out) (g)

- Dried mass, total destruction of sample:
- minimum one natural or drilled hole



-MC pointwise sensor Inserted in samples prior to recording of surface reference values

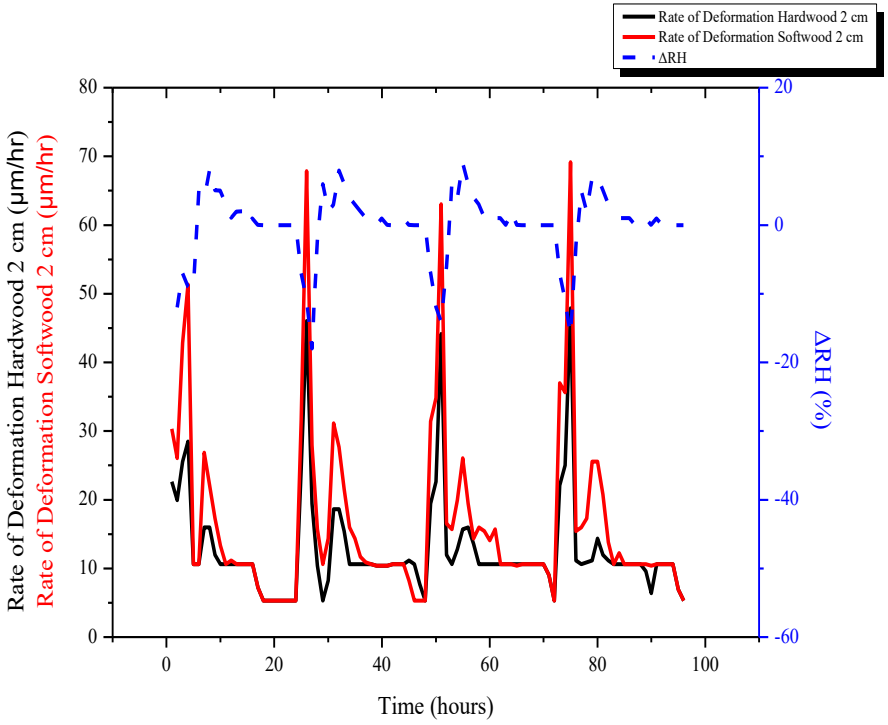
-Rod association to MC

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

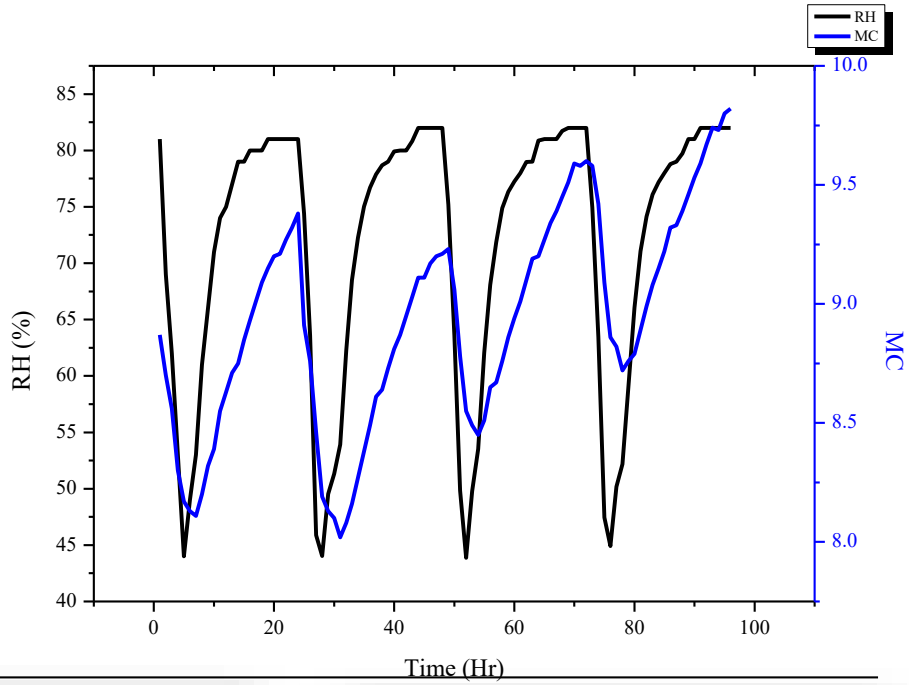
Climate for Culture

Surface measurement of RoD – RH decrease – 24h data for 4 days, zone 1, MC, 2 cm



- Blue dashed line is the change in RH
- larger RH changes result to greatest responses

- Simulated RH vs moisture content as measured by the meter.
- MC follows the variation in RH

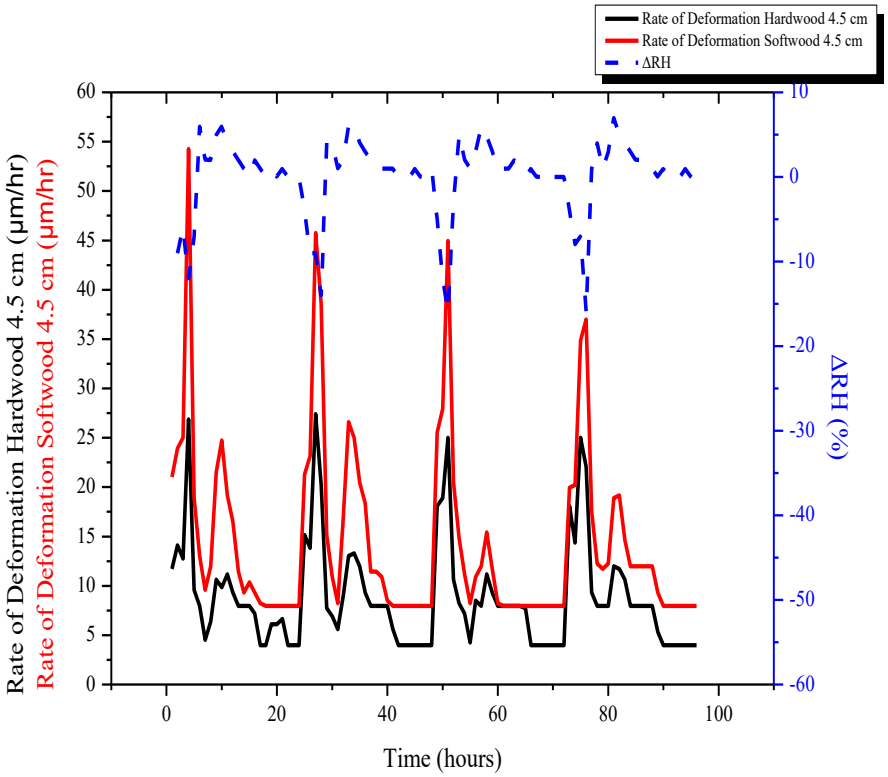


This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

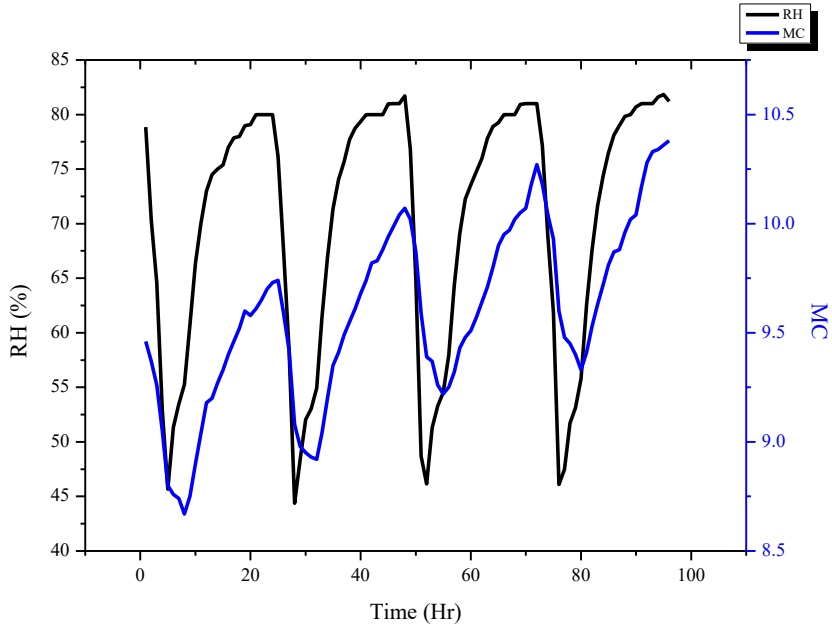
FORTH Institute of Electronic Structure and Laser

Climate for Culture

Surface measurement of RoD – RH decrease – 24h data for 4 days, zone 1, MC, 4.5 cm



1, 2, 4.5 cm results 3 observations:
-the thinner and
-softer the sample is, the more vulnerable it is
-the thicker the sample a difficulty in uptake and output in the humidity environment is observed.



Experimental confirmation:
- Softwood more susceptible than hardwood
- Thinner more vulnerable than thick

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

MC moisture content Comparison between different samples average increase-decrease per cycle

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

1cm	1η Day Start	1η Day	1η Day End	2η Day	2η Day End	3η Day	3η Day End	4η Day	4η Day End
MCmax	10.17		10.3		10.35		10.52		10.59
MCmin		8.84		8.97		9.06		9.17	
% of change		-13%	+17%	-13%	+15%	-12%	+16%	-13%	+15%
	Average decrease 13%								
	Average increase 16%								
2cm	1η Day Start	1η Day	1η Day End	2η Day	2η Day End	3η Day	3η Day End	4η Day	4η Day End
MCmax	8.87		9.38		9.21		9.6		9.82
MCmin		8.11		8.02		8.45		8.72	
% of change		-9%	+16%	-14%	+15%	-8%	+14%	-9%	+13%
	Average decrease 10%								
	Average increase 14%								
4,5cm	1η Day Start	1η Day	1η Day End	2η Day	2η Day End	3η Day	3η Day End	4η Day	4η Day End
MCmax	9.46		9.73		10.07		10.27		10.38
MCmin		8.67		8.92		9.22		9.33	
% of change		-8%	+12%	-8%	+13%	-8%	+11%	-9%	+11%
	Average decrease 9%								
	Average increase 12%								

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Equilibrium values and deformation threshold

Accepted data and conjectures

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

Risk indication is possible through remote ND surface displacement measurements, per:
- different density (light softwood ≈0.30-0.45 , heavier hardwood ≈0.45 -0.65 density)
- different thicknesses

From measured data we accept and assume

- ΔRH% < 5% ⟶ ΔRH=0
- When ΔRH=0 ⟶ Rate of Deformation(R_oD) Stable (Threshold Value, T.V.)
- U=d/t, rate=μm/hr

$$RoD = \begin{Bmatrix} ThresholdValue, \Delta RH = 0 \\ ExperimentValue, \Delta RH > |5\%| \end{Bmatrix}, RoD > 0$$

- Softwood Threshold Value > Hardwood Threshold Value
- 1cm T.V. > 2cm T.V. > 4.5cm T.V.

Impulse response function of Rate of Deformation to external change for RH fluctuations higher to 5%

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

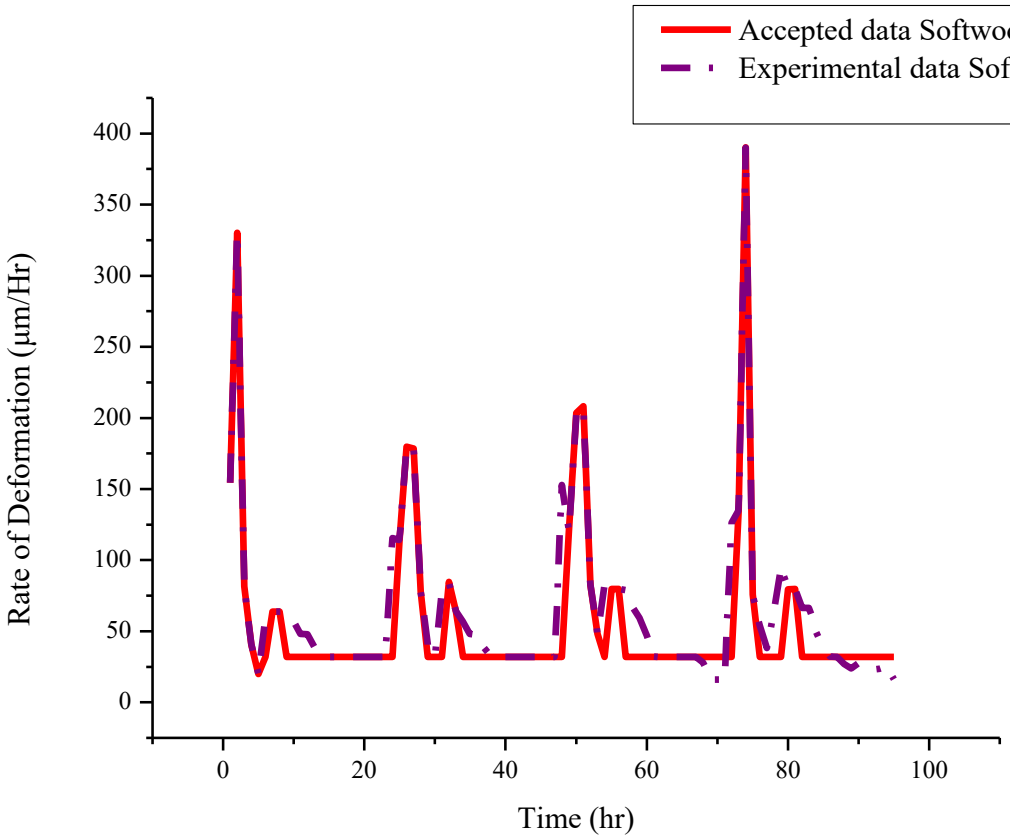
FORTH Institute of Electronic Structure and Laser

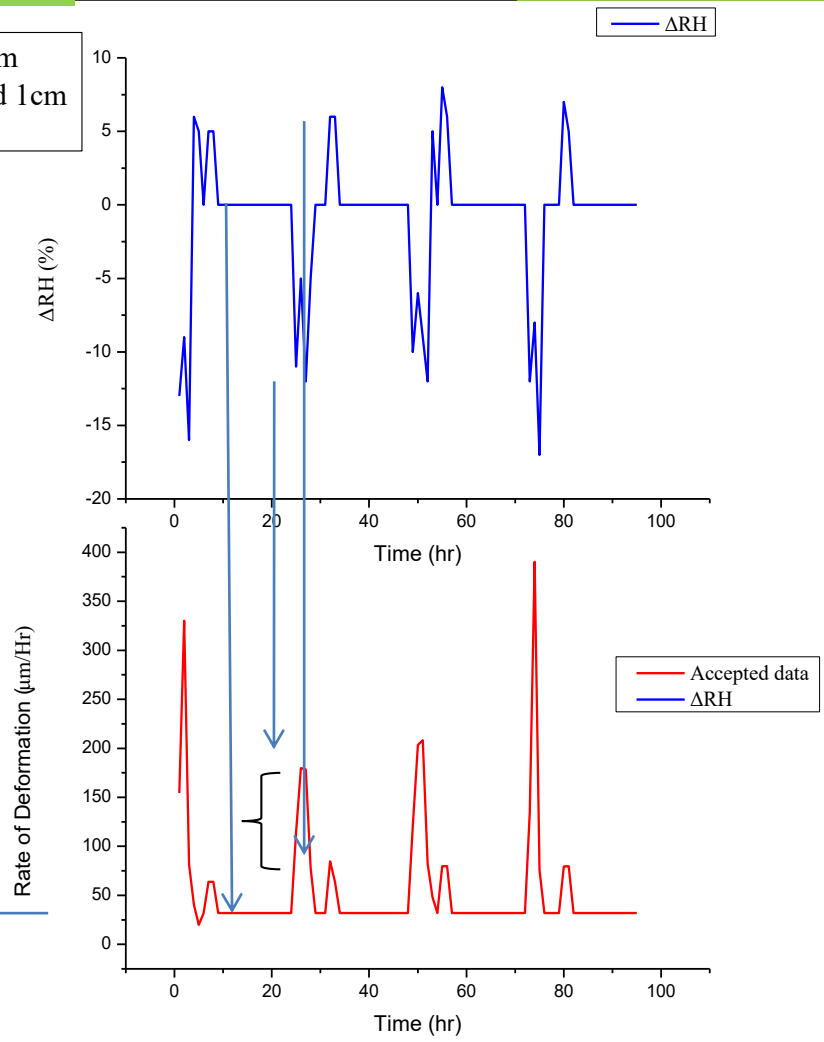
Climate for Culture

Measurement of 24h cycle – shown 24h data for 4 days, zone 1

softwood 1cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece





ΔRH

ΔRH≤-5% = higher RoD

ΔRH=0 , RoD steady

Higher rates on drying out conditions

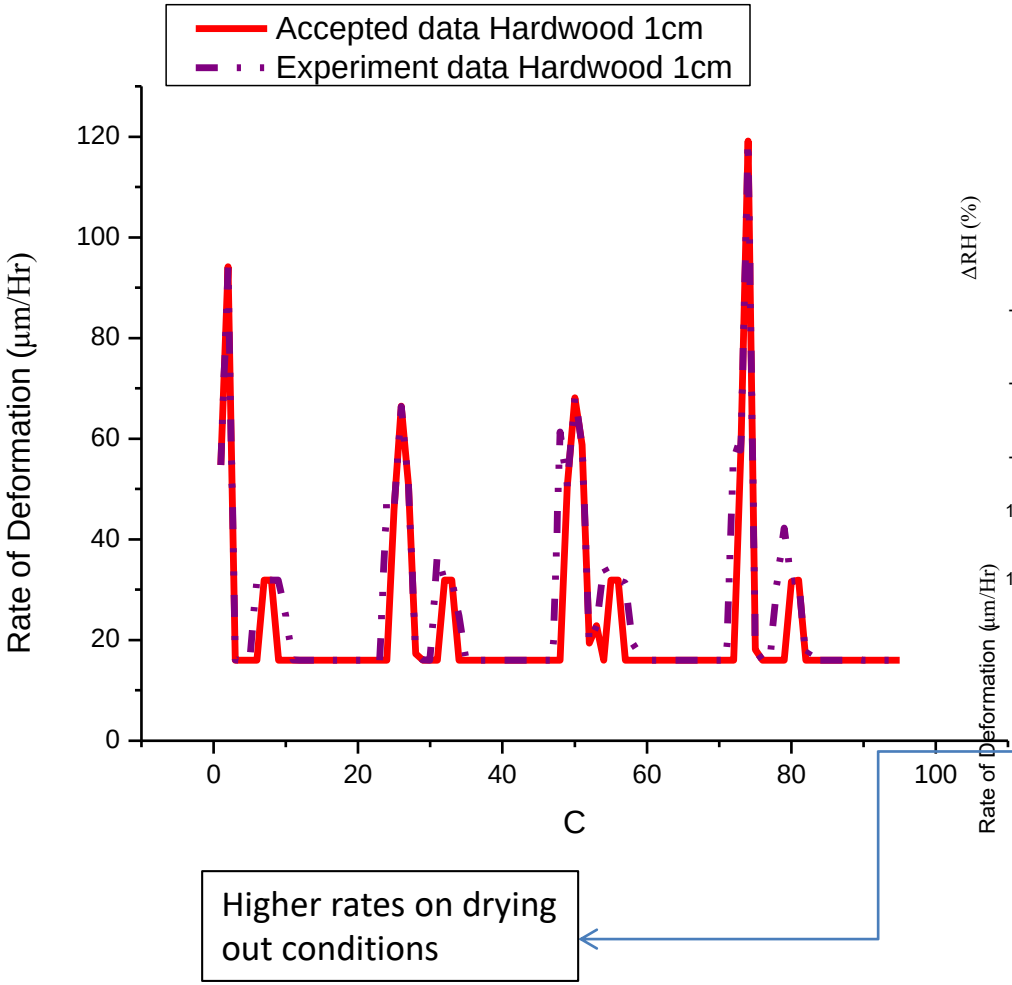
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

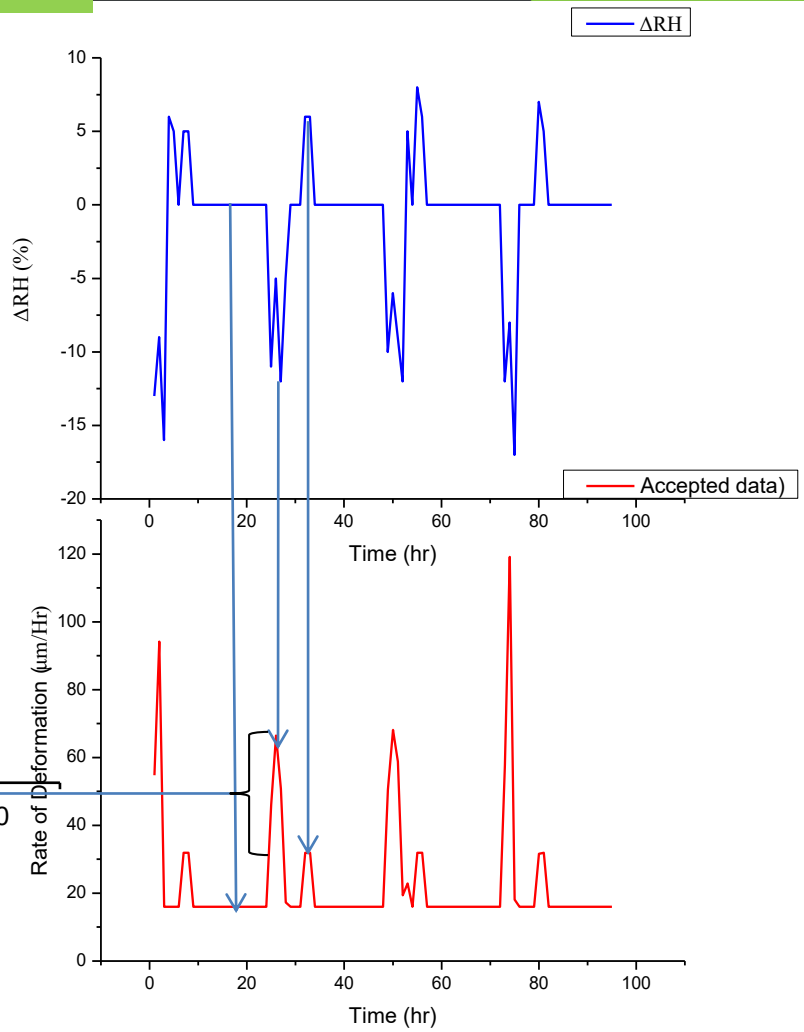
Climate for Culture

Measurement of 24h cycle–24h data for 4 days, zone 1

hardwood 1cm



Higher rates on drying out conditions



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

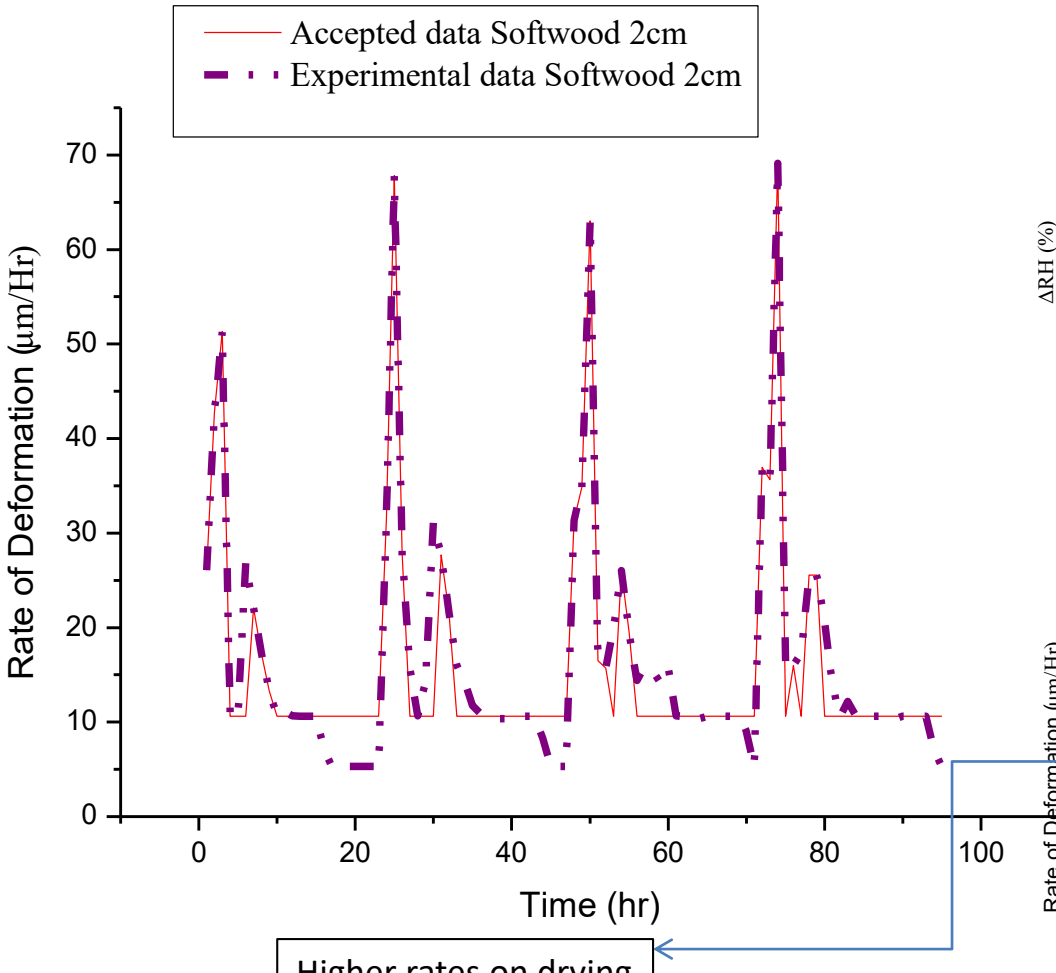
FORTH Institute of Electronic Structure and Laser

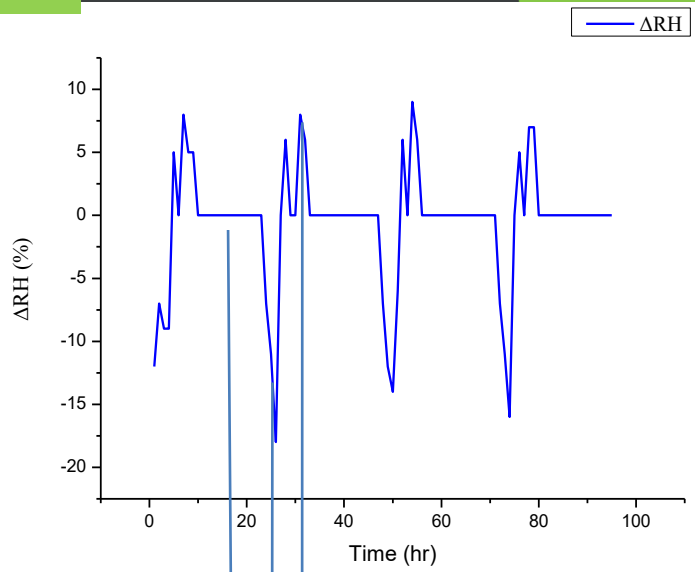
FORTH Foundation for Research & Technology - Hellas

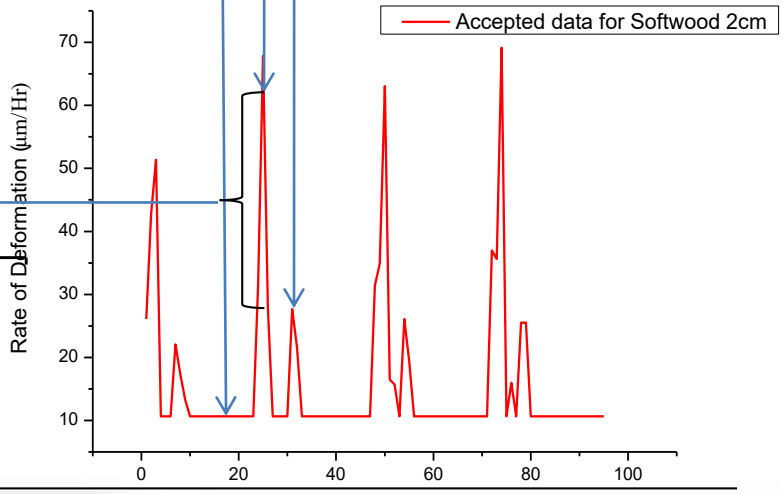
3rd Experiment – 24h cycle – 24h data for 4 days, zone 1

softwood 2cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece







Higher rates on drying out conditions

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

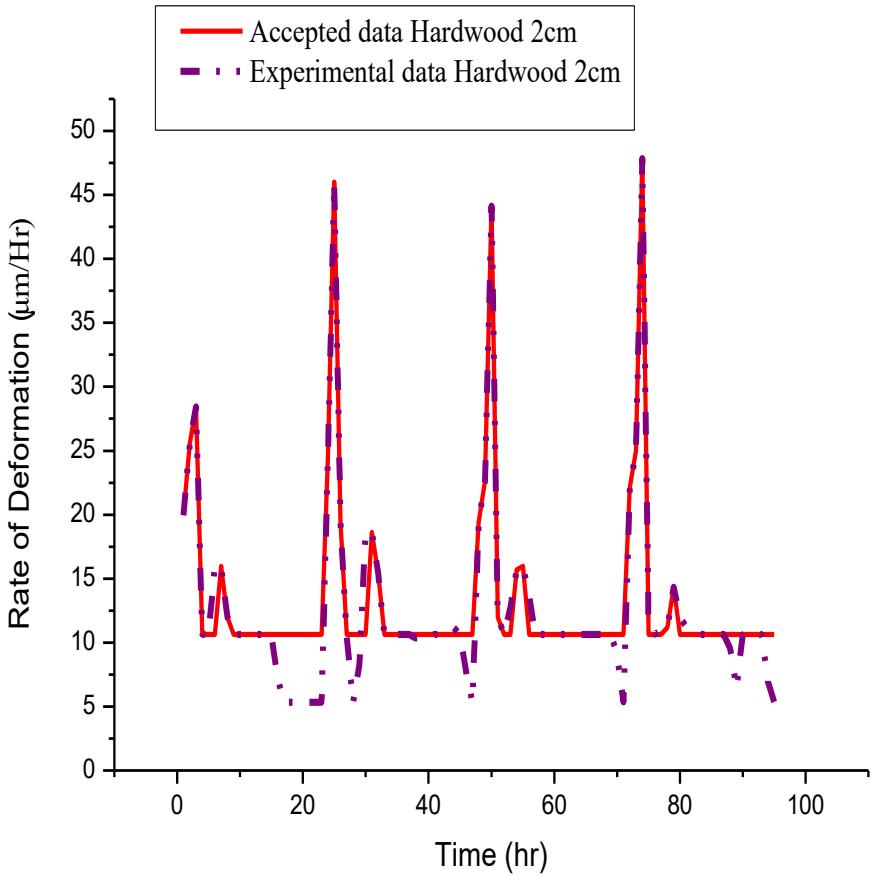
FORTH Institute of Electronic Structure and Laser

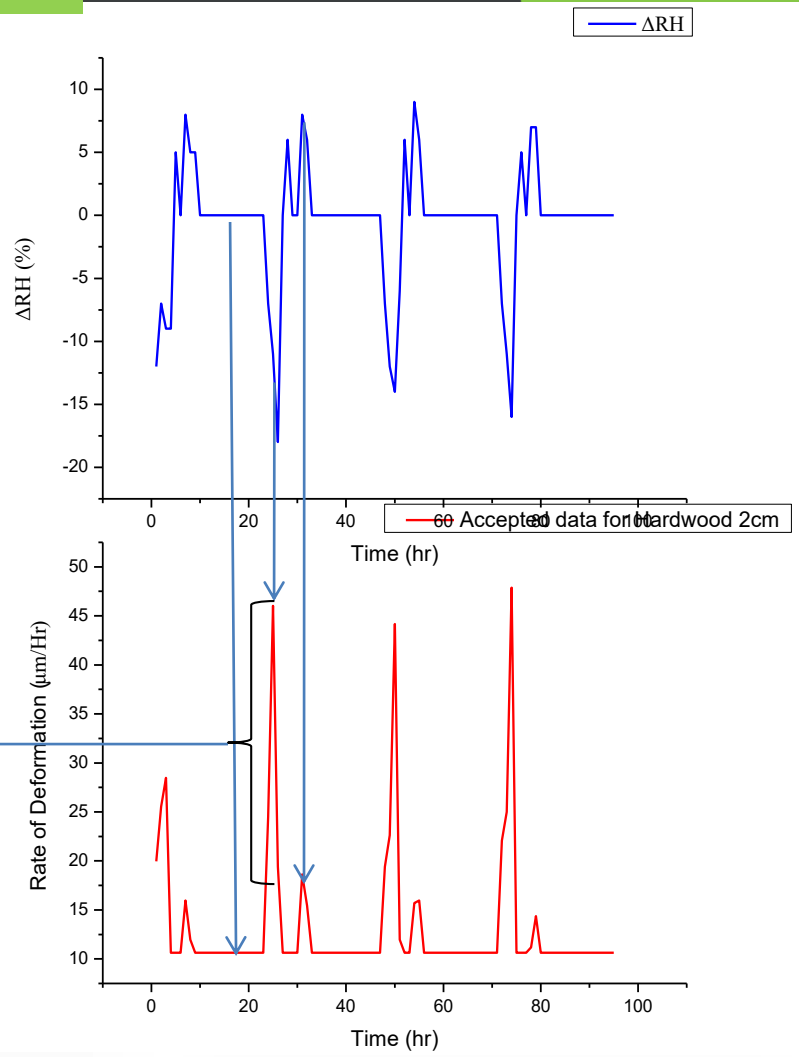
FORTH Foundation for Research & Technology - Hellas

3rd Experiment – 24h cycle – 24h data for 4 days, zone 1

hardwood 2cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece





Higher rates on drying out conditions

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

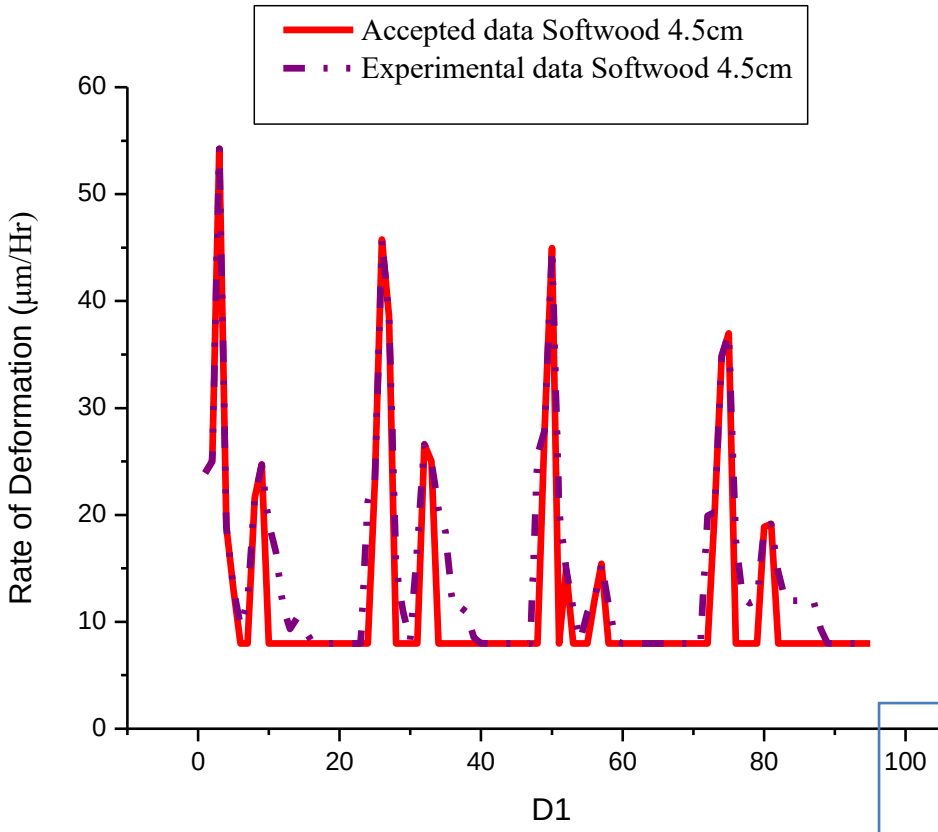
FORTH Institute of Electronic Structure and Laser

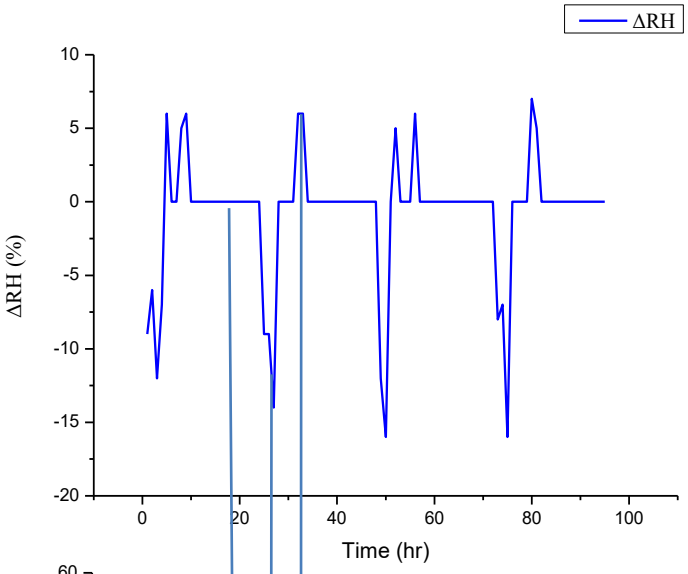
FORTH Foundation for Research & Technology - Hellas

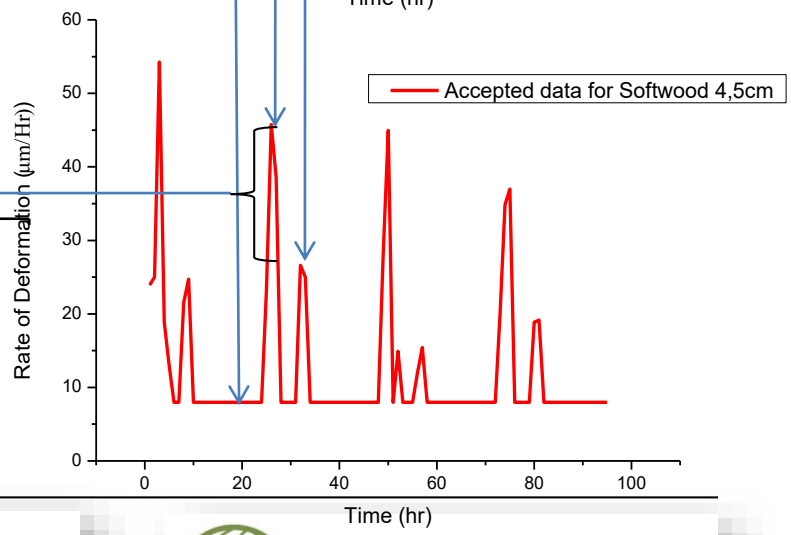
3rd Experiment – 24h cycle – 24h data for 4 days, zone 1

softwood 4.5cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece







Higher rates on drying out conditions

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

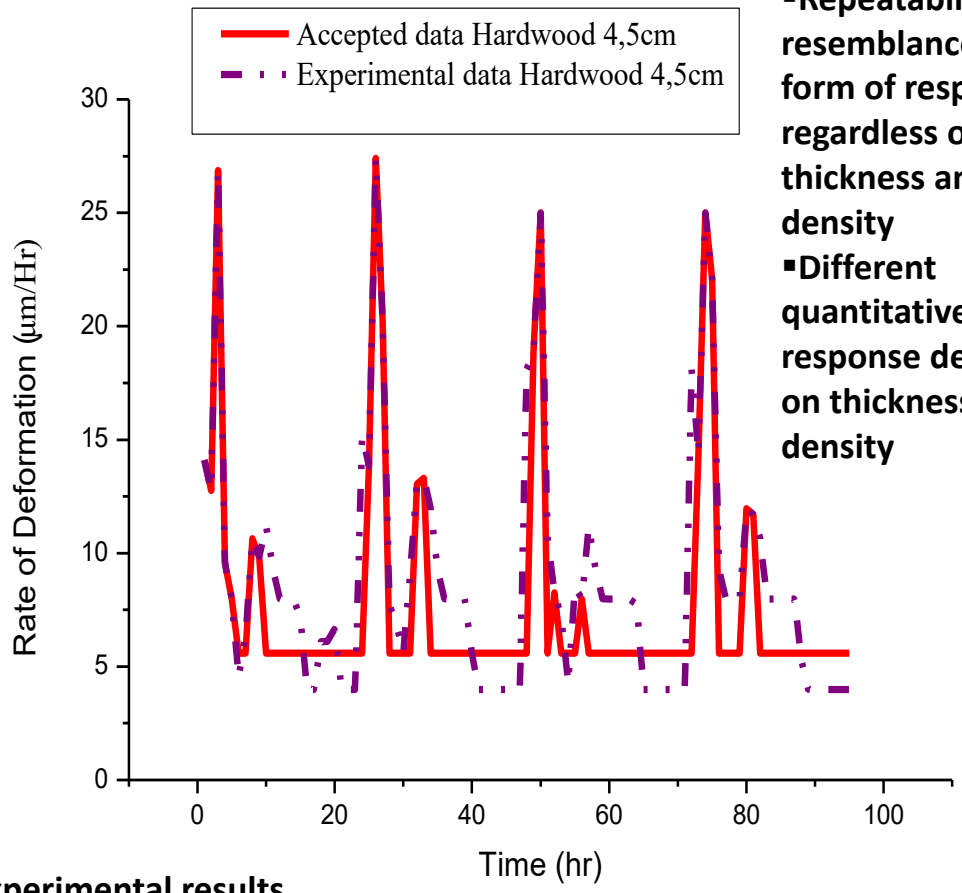
FORTH Institute of Electronic Structure and Laser

Climate for Culture

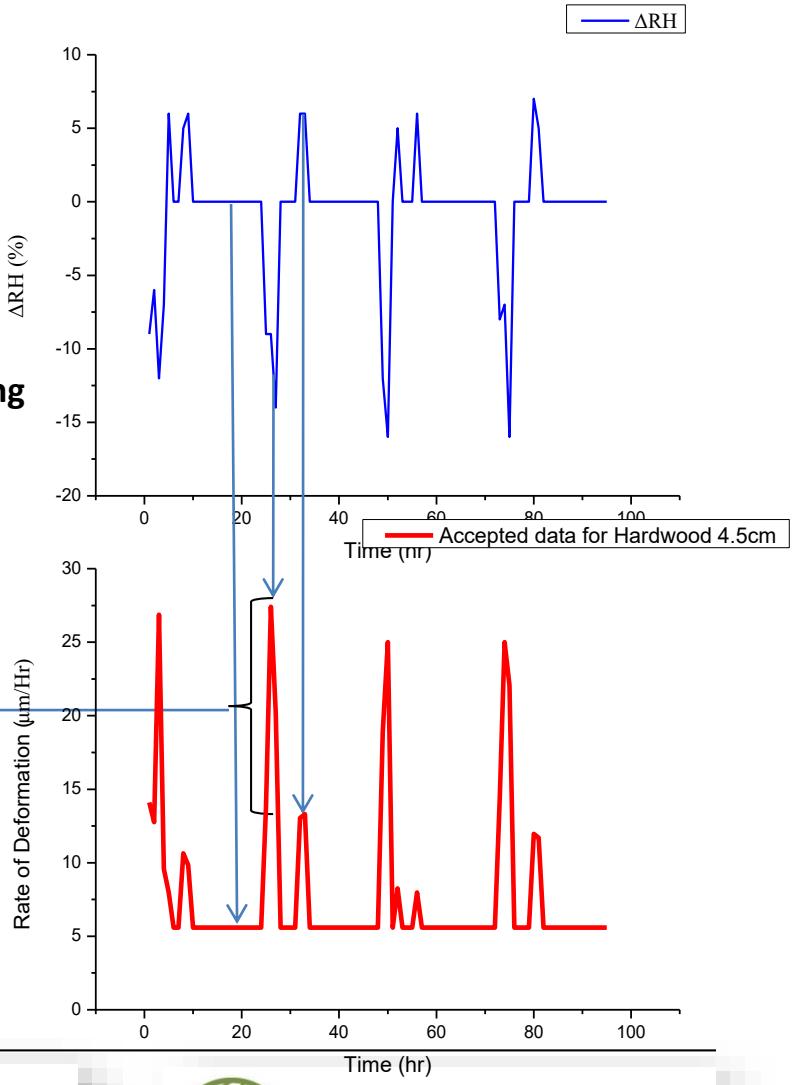
3rd Experiment – 24h cycle – 24h data for 4 days, zone 1

hardwood 4.5cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece



- **Repeatability and resemblance of form of response regardless of thickness and density**
- **Different quantitative response depending on thickness & density**



Experimental results lead to hazard classification

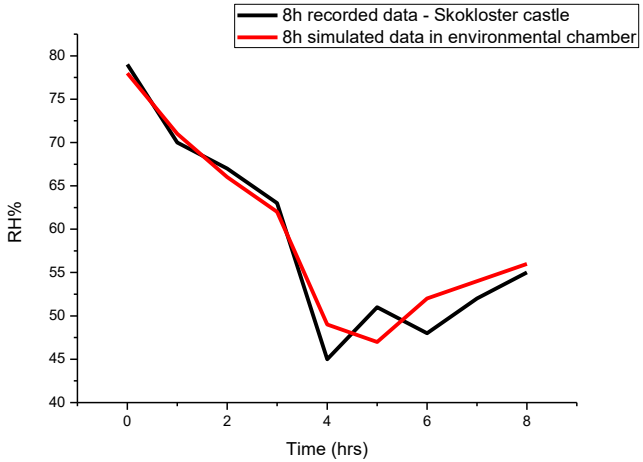
Higher rates on drying out conditions

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

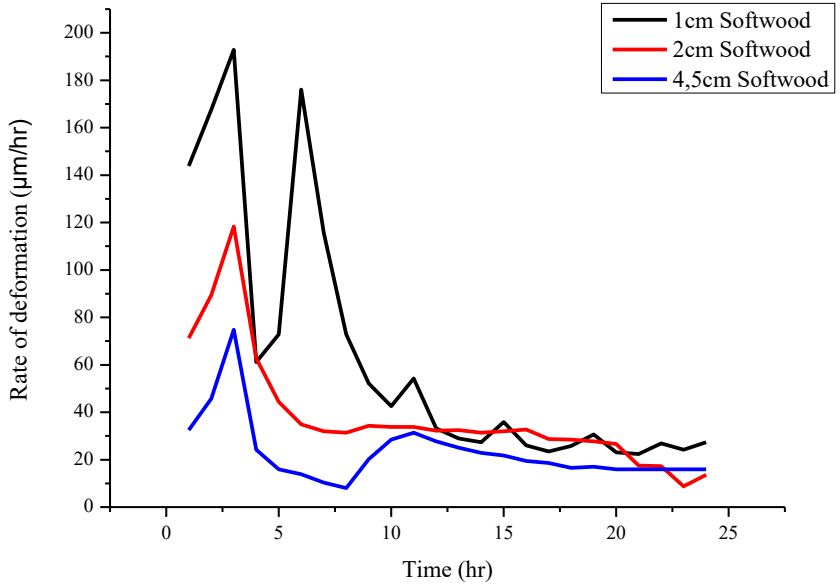
Climate for Culture

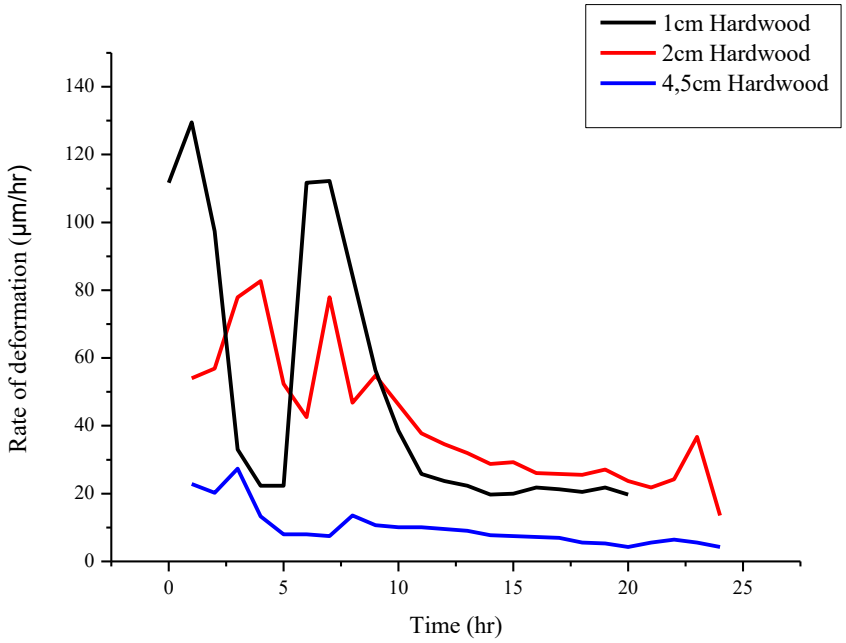
Measured 24h cycle – shown 1 day , zone 1
m & RD, weight & Relative Displacement



Measured data:
max RoD values at max RH decrease

- Weight measurement on balance





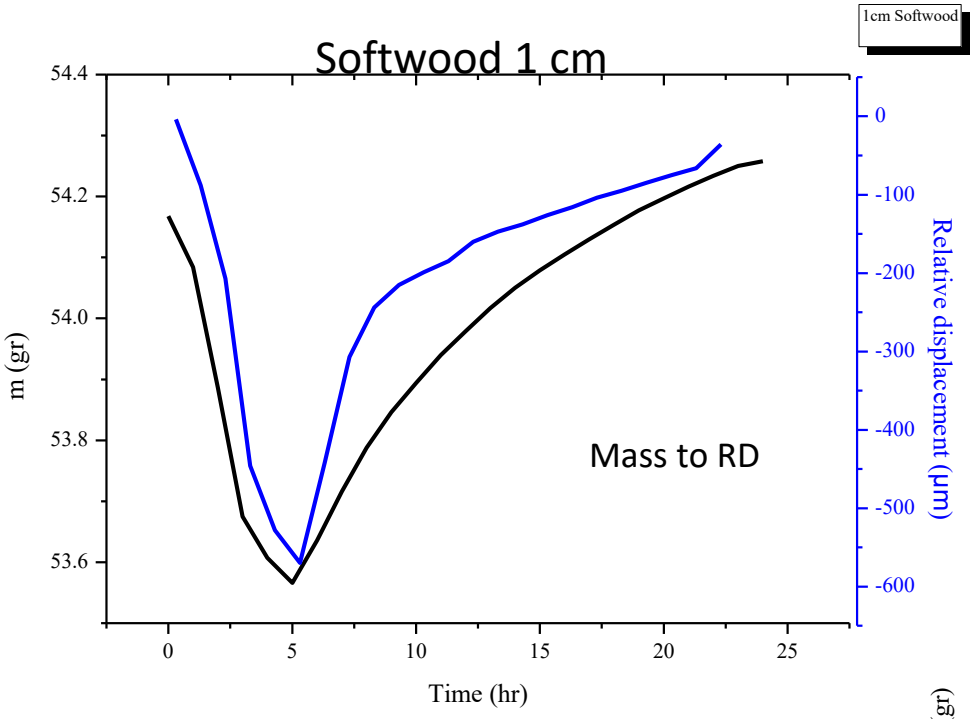
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

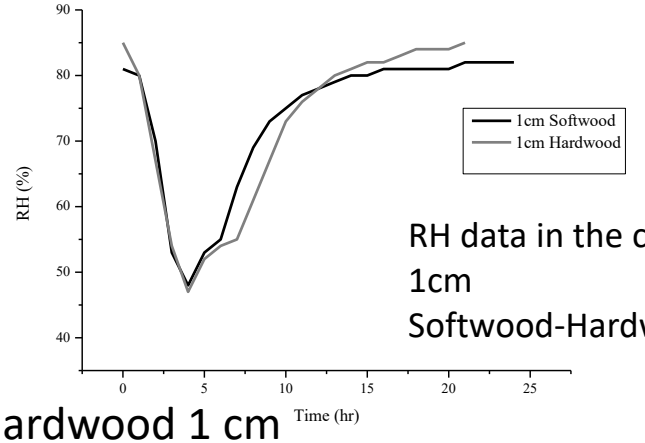
FORTH Institute of Electronic Structure and Laser

Climate for Culture

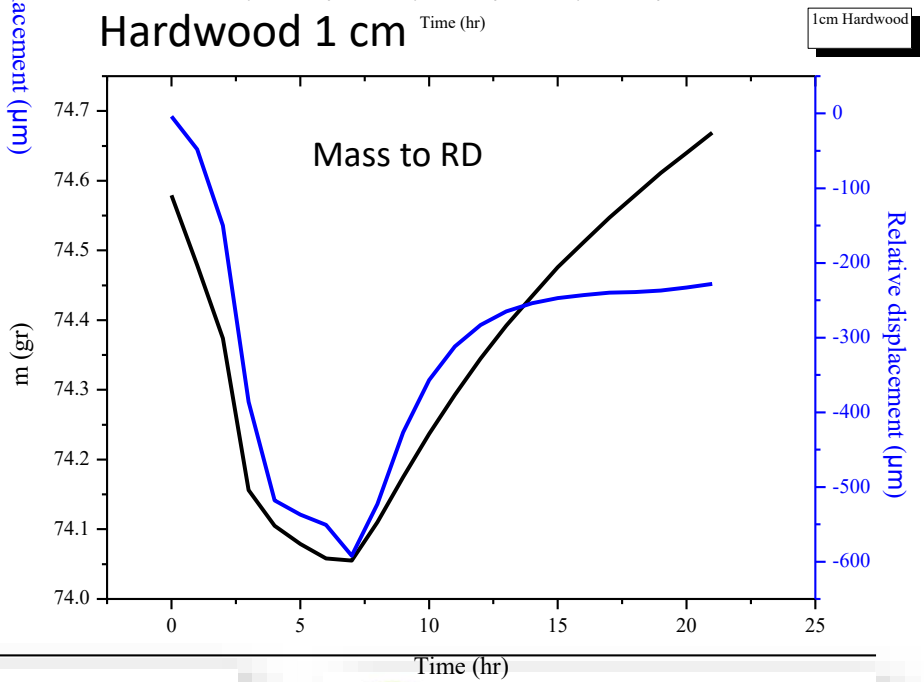
Measured 24h cycle –1 day , zone 1
m & RD, weighting & Relative Displacement
1cm softwood- hardwood on balance

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece





RH data in the chamber
1cm
Softwood-Hardwood



Mass and Relative Displacement follow the RH of the environment

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

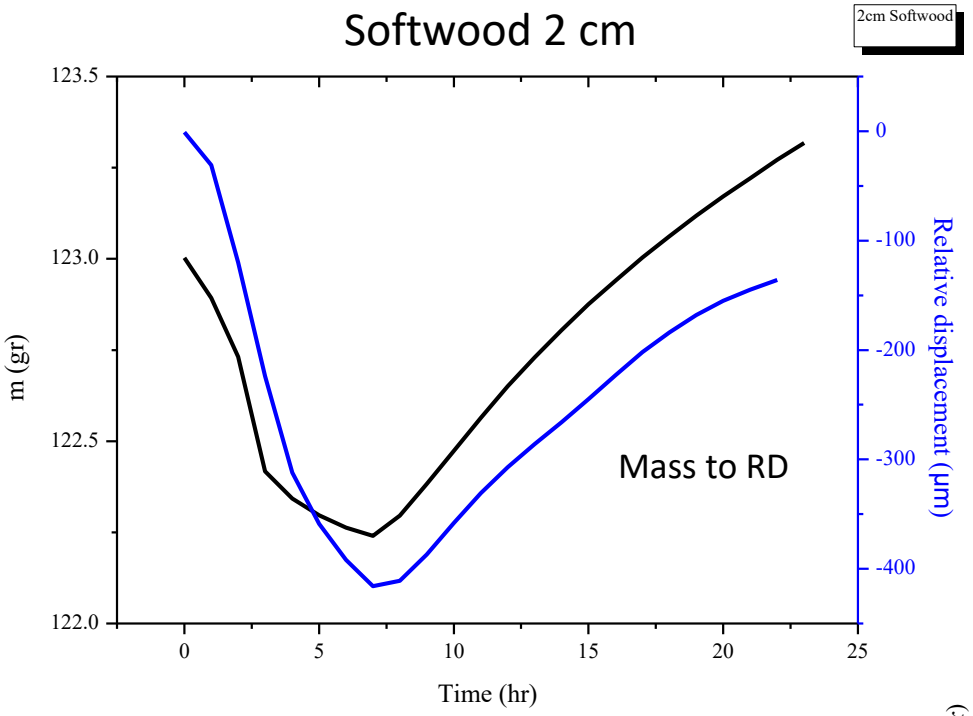
FORTH Institute of Electronic Structure and Laser

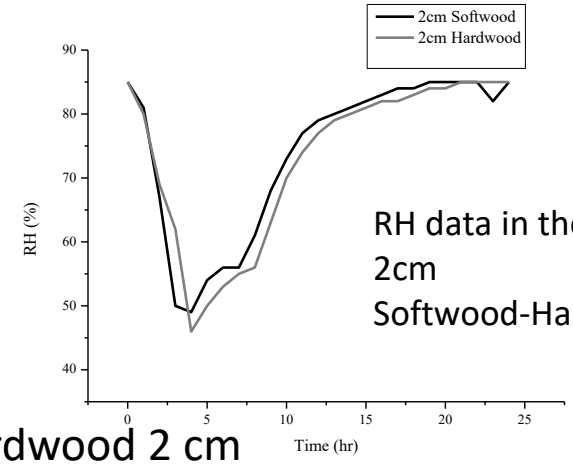
Climate for Culture

Measurement 24h cycle –1 day , zone 1
m & RD, weighting & Relative Displacement
2cm softwood- hardwood

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

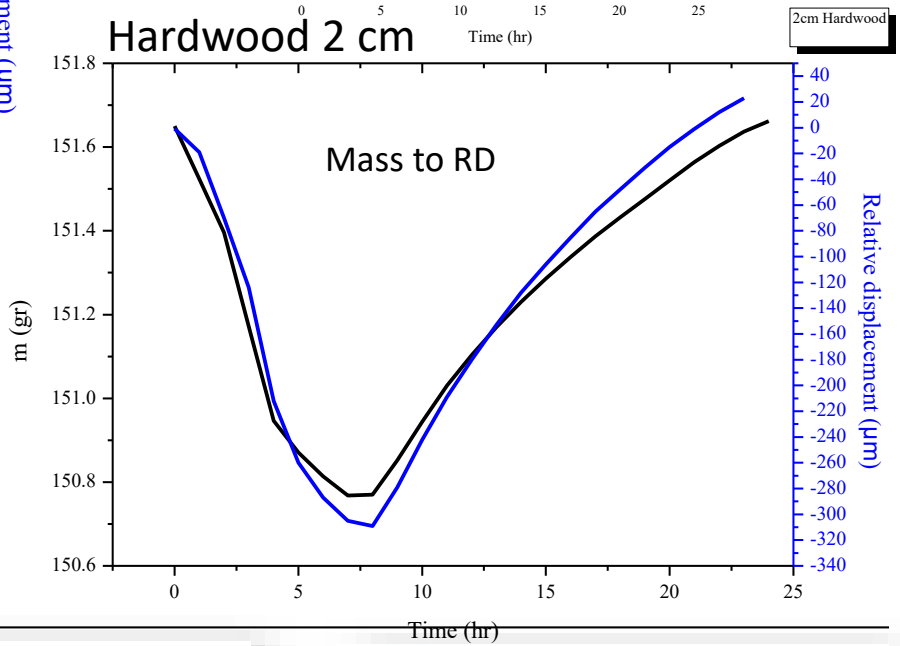
Softwood 2 cm





RH data in the chamber
2cm
Softwood-Hardwood

Hardwood 2 cm



Mass and relative displacement fully follow the RH of the environment

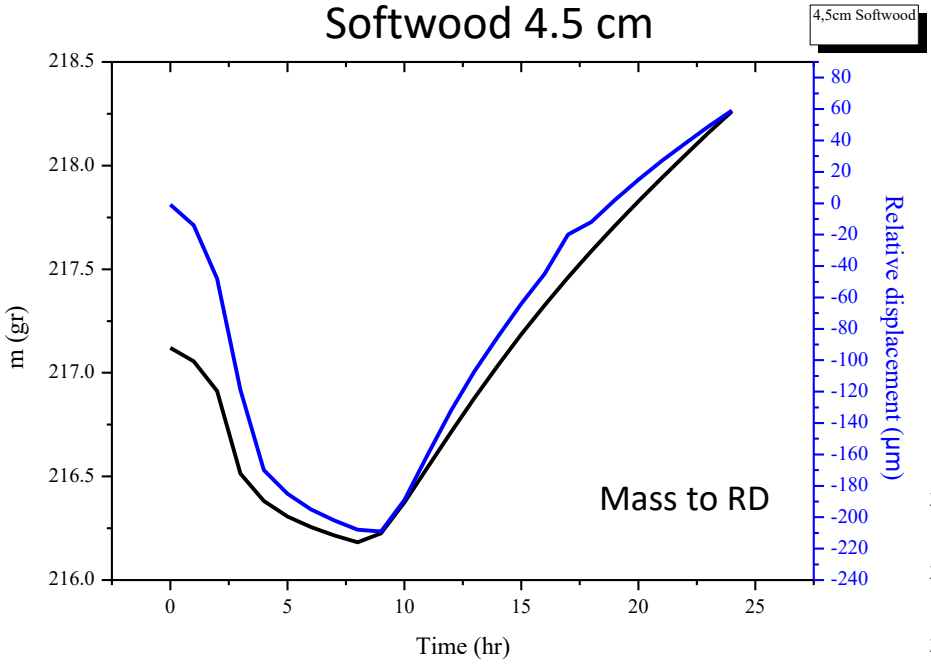
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

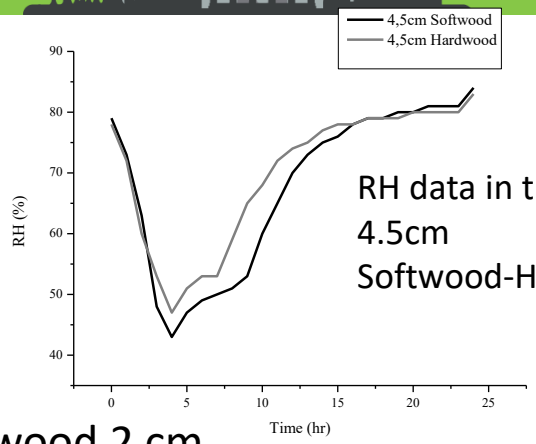
FORTH Institute of Electronic Structure and Laser

FORTH Foundation for Research & Technology - Hellas

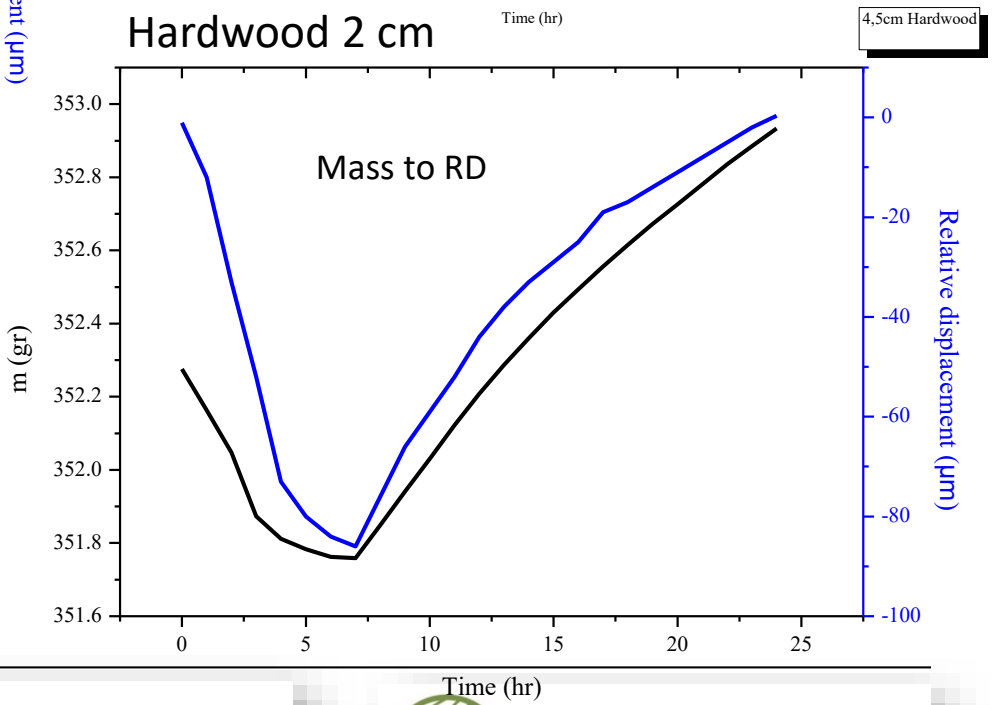
Measurement 24h cycle -1 day , zone 1
m & RD, weighting & Relative Displacement
4.5cm softwood- hardwood

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece





RH data in the chamber
4.5cm
Softwood-Hardwood



Mass and relative displacement fully follow the RH of the environment in all measurements

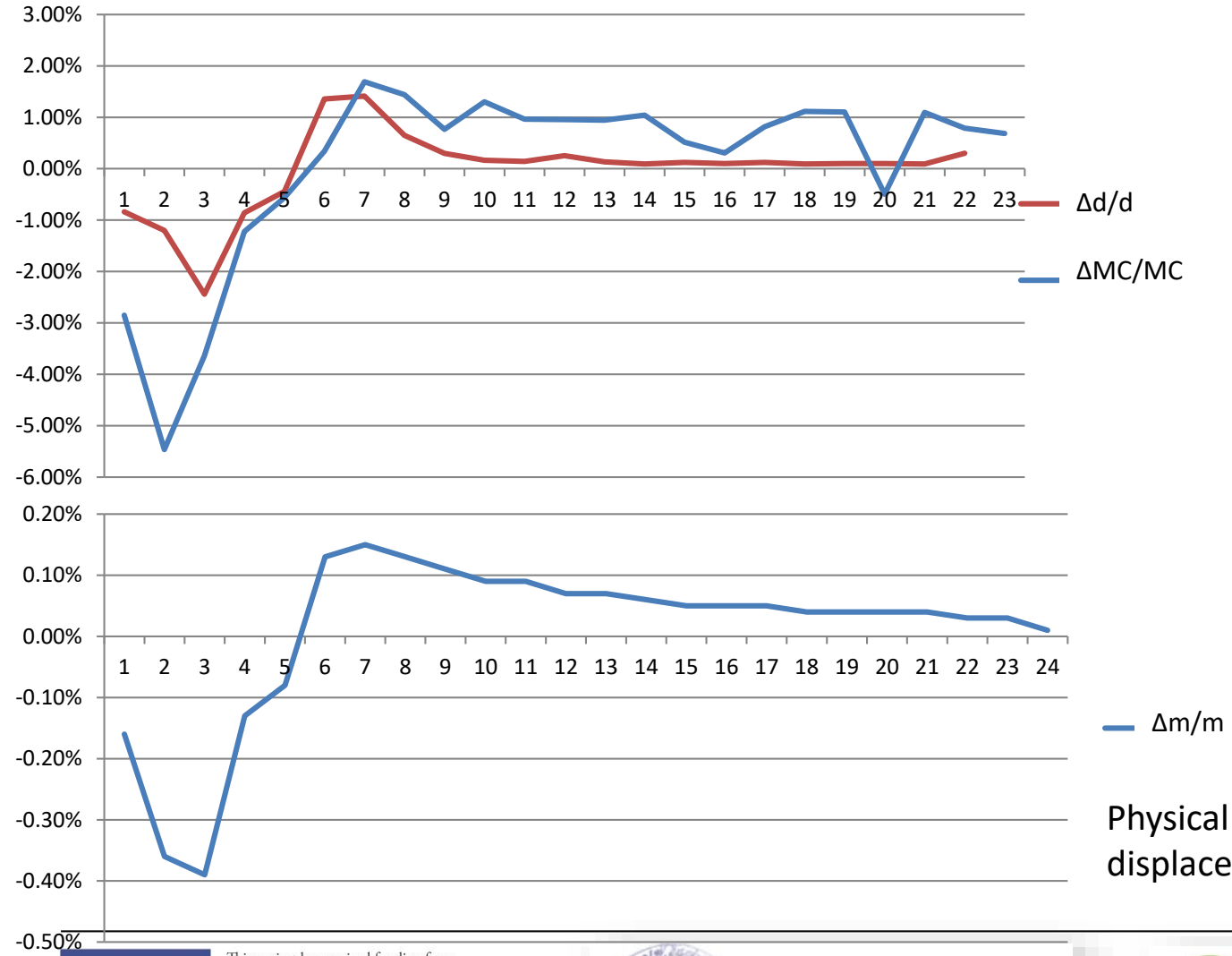
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

FORTH Foundation for Research & Technology - Hellas

Correlation diagram of percentage change per hour: deformation, mass, and MC/ in 24hours cycle Softwood 1 cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece



ΔRd/d	Δm/m	ΔMC/MC
-0.84%	-0.16%	-2.85%
-1.20%	-0.36%	-5.47%
-2.44%	-0.39%	-3.64%
-0.86%	-0.13%	-1.22%
-0.44%	-0.08%	-0.56%
1.36%	0.13%	0.34%
1.41%	0.15%	1.69%
0.65%	0.13%	1.44%
0.30%	0.11%	0.77%
0.16%	0.09%	1.30%
0.14%	0.09%	0.96%
0.25%	0.07%	0.95%
0.13%	0.07%	0.95%
0.09%	0.06%	1.04%
0.12%	0.05%	0.51%
0.10%	0.05%	0.31%
0.12%	0.05%	0.82%
0.09%	0.04%	1.11%
0.10%	0.04%	1.10%
0.10%	0.04%	-0.50%
0.09%	0.04%	1.10%
0.30%	0.03%	0.79%

Physical quantities and relative displacement follow same alterations

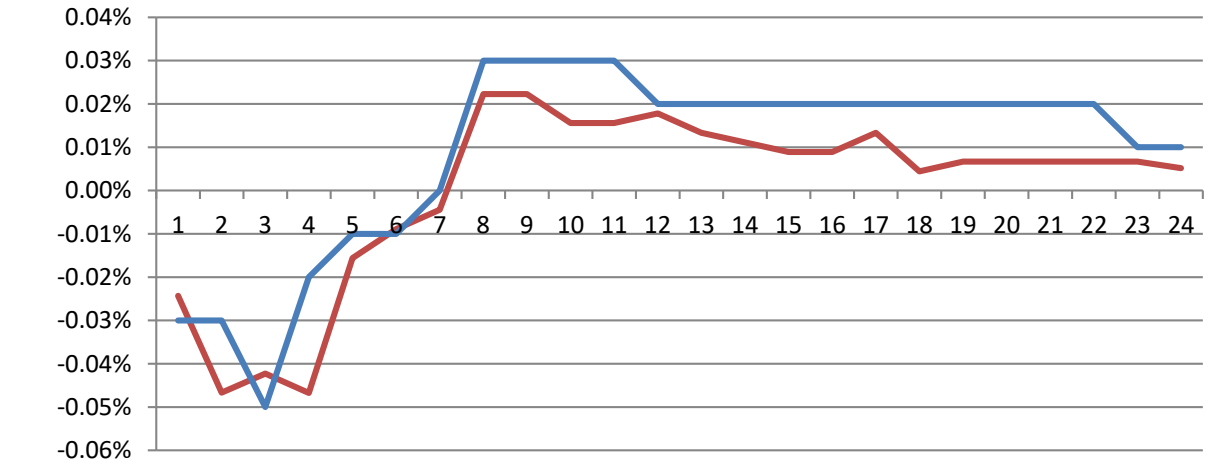
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Correlation diagram of percentage change per hour: deformation, mass, and MC/ in 24hours cycle hardwood 4.5 cm

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece



Δd/d	Δm/m	ΔMC/MC
-0.02%	-0.03%	-0.95%
-0.05%	-0.03%	-1.17%
-0.04%	-0.05%	-2.27%
-0.05%	-0.02%	-2.76%
-0.02%	-0.01%	-0.45%
-0.01%	-0.01%	-0.23%
0.00%	0.00%	-0.80%
0.02%	0.03%	0.92%
0.02%	0.03%	1.71%
0.02%	0.03%	1.57%
0.02%	0.03%	1.55%
0.02%	0.02%	0.22%
0.01%	0.02%	0.76%
0.01%	0.02%	0.65%
0.01%	0.02%	0.75%
0.01%	0.02%	0.64%
0.01%	0.02%	0.63%
0.00%	0.02%	0.84%
0.01%	0.02%	-0.21%
0.01%	0.02%	0.31%
0.01%	0.02%	0.42%
0.01%	0.02%	0.52%
0.01%	0.01%	0.31%
0.01%	0.01%	0.00%

Physical quantities and relative displacement follow same alterations

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Max & Average of: deformation Δd/d

	Δd/d					
	4,5cm Hardwood	4,5cm Softwood	2cm Hardwood	2cm Softwood	1cm Hardwood	1cm Softwood
	-0.02%	-0.03%	-0.09%	-0.15%	-0.44%	-0.84%
	-0.05%	-0.08%	-0.26%	-0.45%	-1.02%	-1.19%
	-0.04%	-0.16%	-0.27%	-0.52%	-2.36%	-2.39%
	-0.05%	-0.11%	-0.44%	-0.44%	-1.32%	-0.82%
	-0.02%	-0.03%	-0.24%	-0.24%	-0.19%	-0.42%
	-0.01%	-0.02%	-0.14%	-0.17%	-0.14%	1.28%
	0.00%	-0.02%	-0.09%	-0.12%	-0.41%	1.35%
	0.02%	-0.01%	-0.02%	0.03%	0.69%	0.63%
	0.02%	0.00%	0.15%	0.12%	0.96%	0.29%
	0.02%	0.04%	0.19%	0.15%	0.70%	0.16%
	0.02%	0.06%	0.17%	0.14%	0.45%	0.14%
	0.02%	0.06%	0.15%	0.12%	0.29%	0.25%
	0.01%	0.06%	0.14%	0.11%	0.18%	0.13%
	0.01%	0.05%	0.13%	0.10%	0.11%	0.09%
	0.01%	0.05%	0.11%	0.11%	0.07%	0.12%
	0.01%	0.04%	0.11%	0.11%	0.04%	0.10%
	0.01%	0.06%	0.10%	0.11%	0.03%	0.12%
	0.00%	0.02%	0.09%	0.09%	0.01%	0.09%
	0.01%	0.03%	0.09%	0.08%	0.02%	0.10%
	0.01%	0.03%	0.08%	0.07%	0.04%	0.10%
	0.01%	0.03%	0.07%	0.05%	0.05%	0.09%
Abs Average	**0.02%**	**0.04%**	**0.13%**	**0.16%**	**0.45%**	**0.49%**
max %	**-0.05%**	**-0.16%**	**-0.44%**	**-0.52%**	**-2.36%**	**-2.39%**

Where:

$\Delta d = RD_{i+1} - RD_i$

d =the thickness of sample

- Relative displacement and rate of displacement confirm the thick hardwood -density and type of wood- less susceptible to RH change
- 4.5 hardwood max 0.05% compared to 1 cm softwood with max 2.4%
- Max values are obtained at maxΔRH at 4^{th}-5^{th} hour of cycle

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

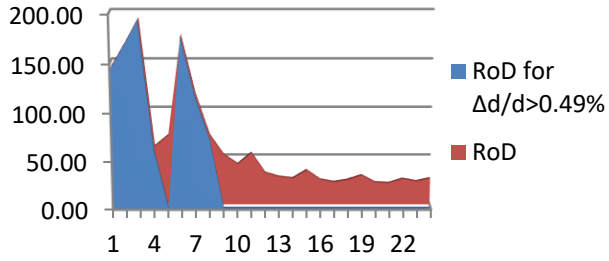
FORTH Institute of Electronic Structure and Laser

Climate for Culture

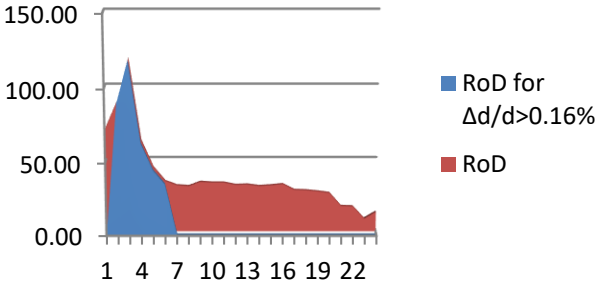
Diagrams of Rate of deformation vs mean absolute values

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

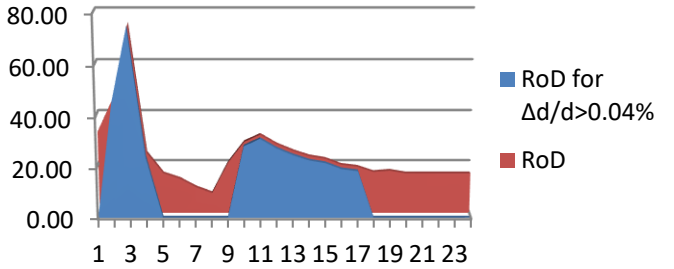
1cm softwood



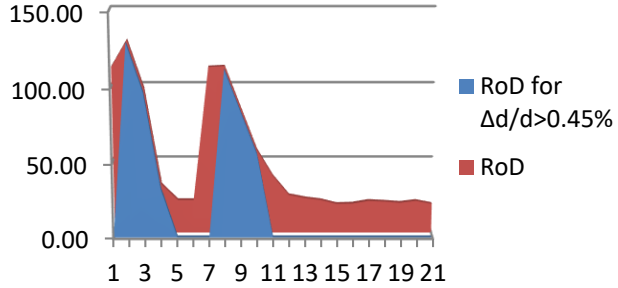
2cm softwood



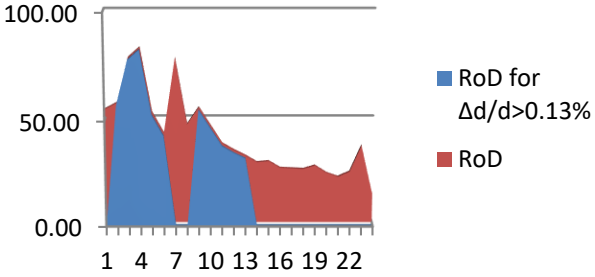
4,5cm softwood



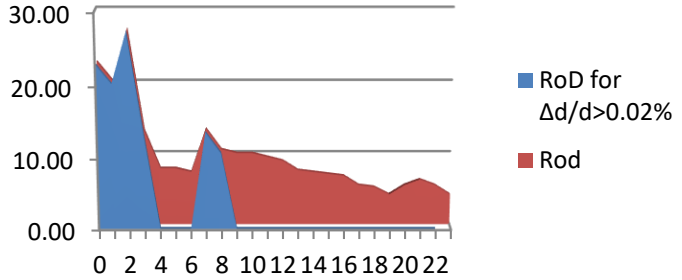
1cm hardwood



2cm hardwood



4,5cm hardwood



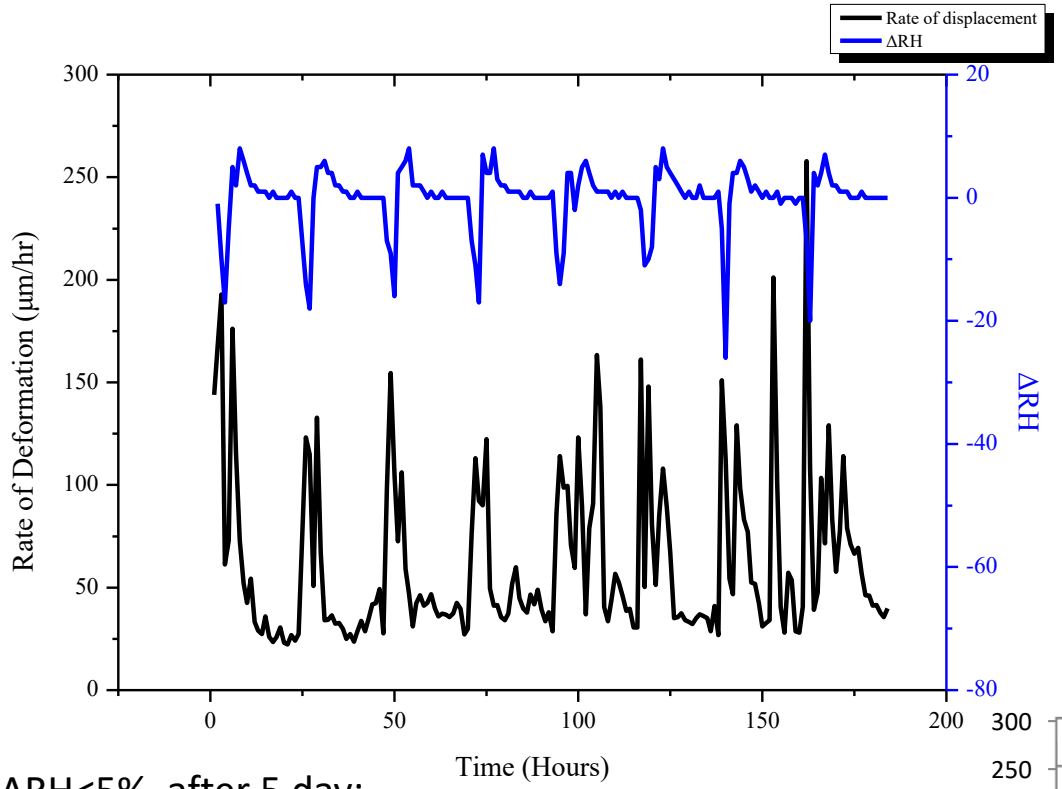
- Diagrams of RoD for 24h cycle with the values of the mean absolute values of deformation confirm the methodology to use the Rate of Deformation for risk assessment.
- the higher rates of deformation correspond to deformations higher of the mean accepted value
- **Threshold Values can be assigned individually from rate of deformation**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

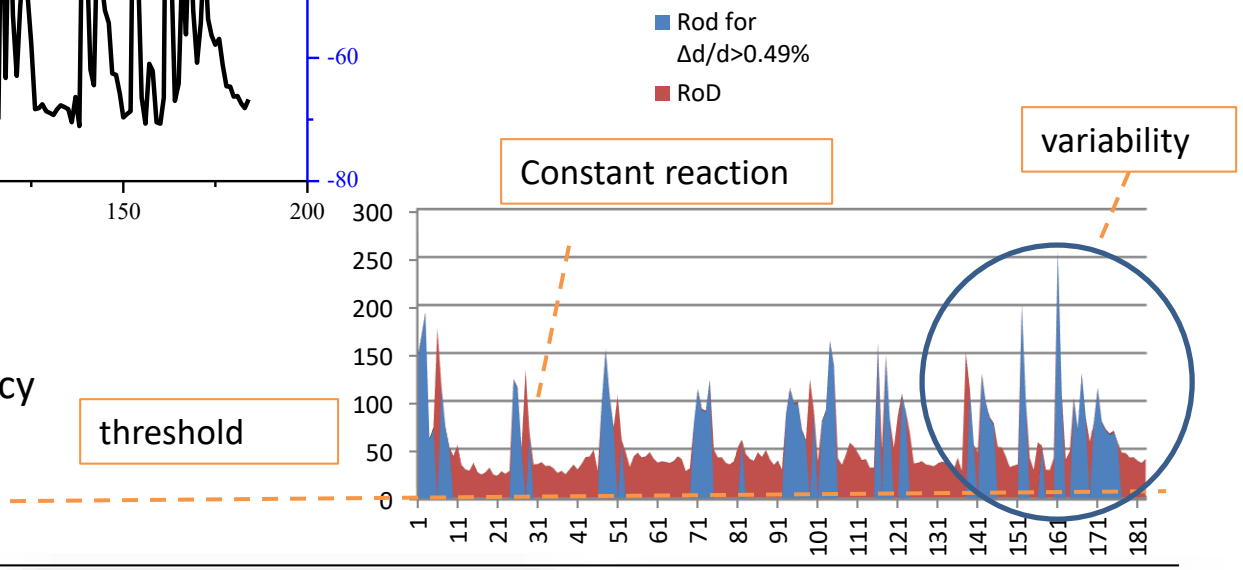
Rate of deformation above the threshold value without loading



•Rate of deformation above the threshold value with negligible loading

Where:
$\Delta d = RD_{i+1} - RD_i$
d =1000μ (the initial thickness of sample)

•After day 5: The rate of change increases and become denser within the 24-hour cycle even at stable values (ΔRH<5%)



ΔRH<5% after 5 day:
•Variability in speed of reactions
•Variability in amplitude and frequency in rate of deformation above the threshold value

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Conclusions

CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE: FACING THE CHALLENGE
International Conference
June 21-22, 2019
Zappeion Megaron, Athens, Greece

- Measurements provide systematic and repeatable data
- Rate of displacement from surface measurements as risk indicator is confirmed
- Materials of same properties but different characteristic are detectable and responses diversity accessible
- The lighter and thinner the wood the more susceptible to RH changes is
- Shrinking promotes higher rates of deformation
- Repeatable drying-out accumulates fatigue even in threshold values (≈5%ΔRH) considered as safe
- Small and smooth but constant loading may not be negligible for materials impact but kicks off changes in material reaction
- Risk index can be expected from ND remote DHSPI measurements of surfaces

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH Institute of Electronic Structure and Laser

Climate for Culture

Thank you for your attention

FORTH
Institute of Electronic Structure and Laser

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 226973

FORTH
Institute of Electronic Structure and Laser

Climate for Culture