Climate for Culture

Numerical Modelling of the Damage Potential of Indoor Climate Variations to a Historic Wooden Cabinet

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Where innovation starts

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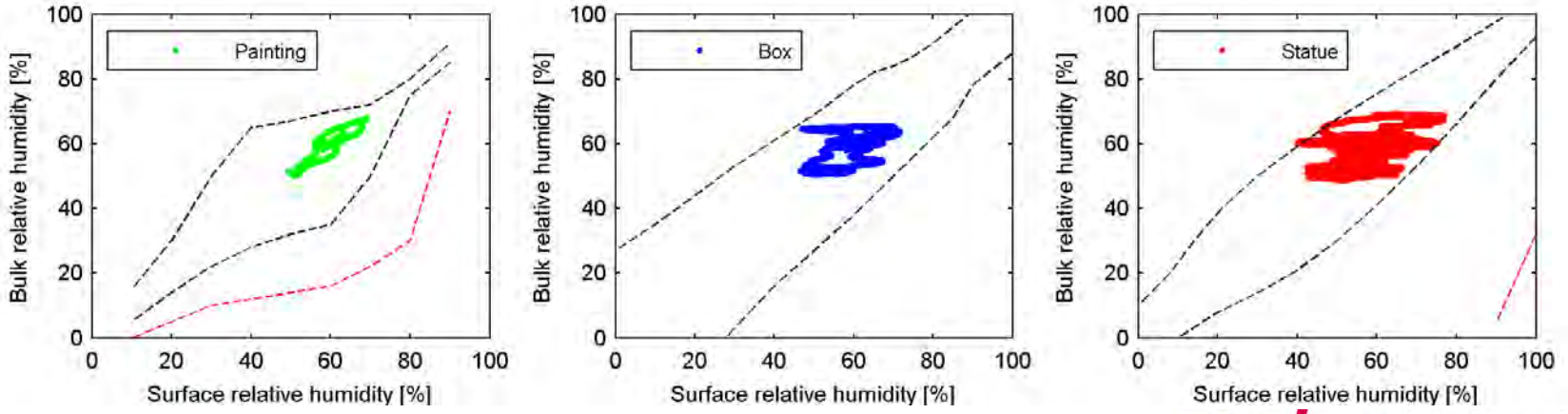
Introduction

Museum objects

- Risks of biological, chemical and mechanical degradation due to wrong indoor climate conditions

Prediction of mechanical stress related to climate variations

- Analysis of hygroscopic and mechanical behaviour of objects
- Definition of tolerable fluctuations of relative humidity

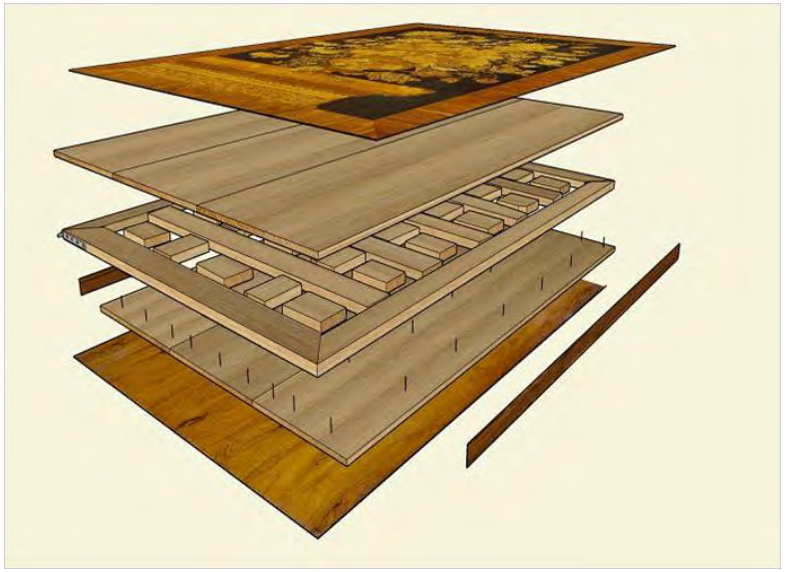


Sources:
Panel painting: Mecklenburg et al. (1998)
Lacquer Box: Bratasz et al. (2009)
Wooden Statue: Kozlowski (2007)
Graphical representation: Martens (2011)

Case study

Van Mekeren Cabinet

- Situated in Grand Salon, Amerongen Castle, The Netherlands
- Created by Jan van Mekeren around 1690-1710



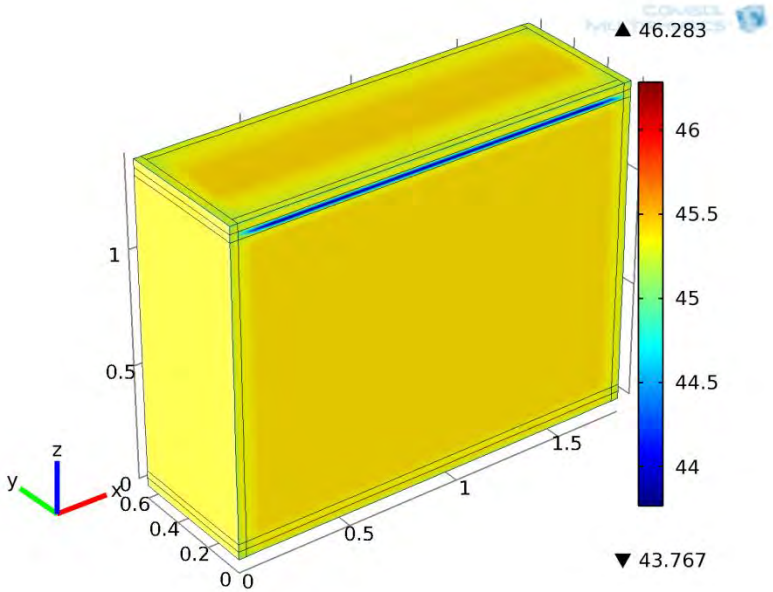
Objectives

- To analyse the response time of a door panel to a sudden relative humidity increase
- To analyse the microclimate conditions around the cabinet as a results of the indoor climate conditions in the Grand Salon
- To predict deformation of a door panel due to climate variations

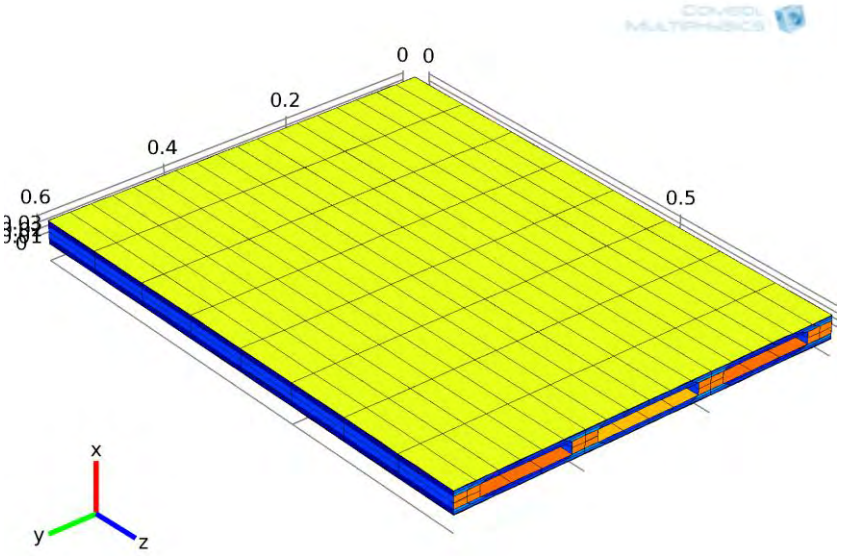
⇨ Validation with **on-site measurements**

COMSOL modelling

- **Heat transfer in solids and fluids module**
- **Structural mechanics module**



3D model of cabinet



3D model of door panel

COMSOL modelling

- **Heat and moisture transport**

$$\rho c_p \frac{\partial T}{\partial t} = \nabla(k \nabla T)$$

$$\frac{\partial Pv}{\partial t} = \nabla(D(Pv) \nabla Pv)$$

ρ	=	density [kg/m³]
c_p	=	specific heat capacity [J/kgK]
T	=	temperature [°C]
K	=	thermal conductivity [W/mK]
Pv	=	vapour pressure [Pa]
D(P)	=	moisture diffusion coefficient [m²/s]

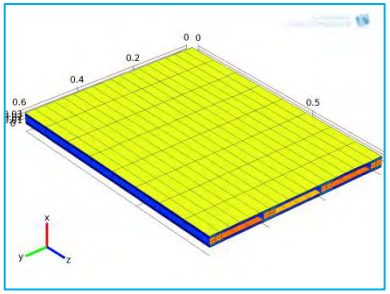
COMSOL modelling

- **Stress and strain**

$$\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{pmatrix} = \begin{pmatrix} \frac{1}{E_x} & -\frac{\nu_{xy}}{E_Y} & 0 \\ -\frac{\nu_{yx}}{E_x} & \frac{1}{E_y} & 0 \\ 0 & 0 & \frac{1}{G_{xy}} \end{pmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} + \begin{pmatrix} \alpha_x \\ \alpha_y \\ 0 \end{pmatrix} \Delta\theta + \begin{pmatrix} \kappa_x \\ \kappa_y \\ 0 \end{pmatrix} \Delta w$$

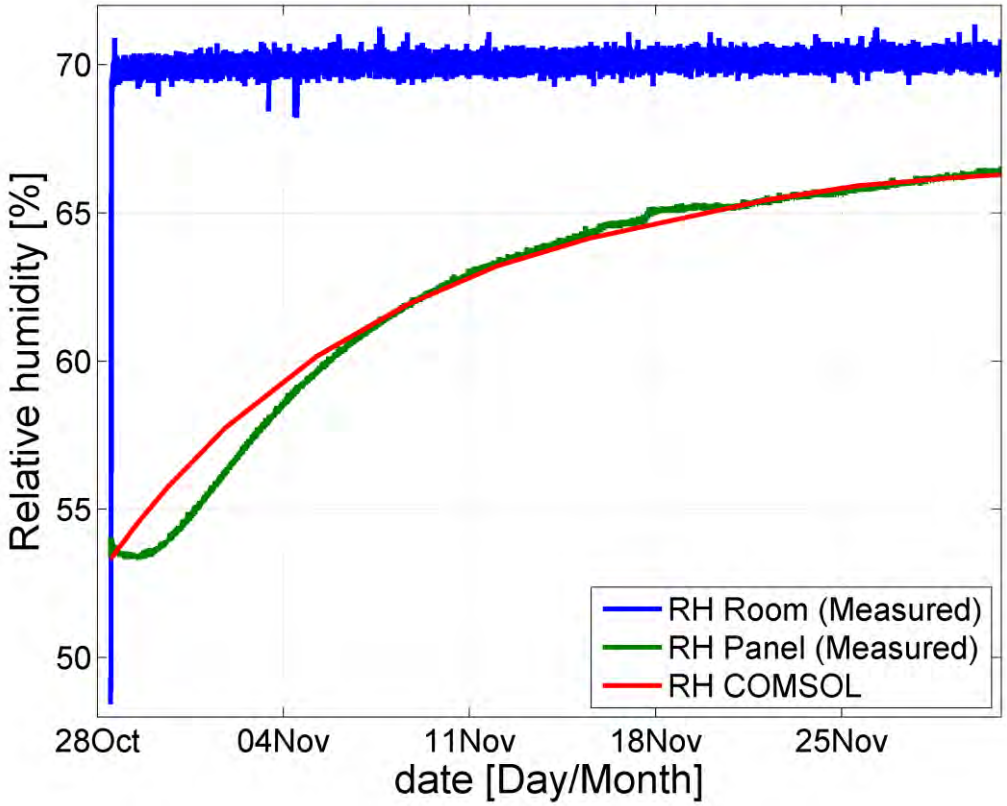
$\varepsilon_x \varepsilon_y$	=	normal strain components [-]
γ_{xy}	=	shear strain component associated with two axis [-]
ν_{xy}, ν_{yx}	=	Poisson's ratio [-]
E_x, E_y	=	Young's moduli [N/m²]
G_{xy}	=	shear modulus [N/m²]
α_x, α_y	=	linear thermal expansivity [m/mK]
θ	=	temperature [°C]
κ_x, κ_y	=	linear deformation due to changes in moisture content [m/m(kg/m³)]
w	=	moisture content [kg/m³]

Response time

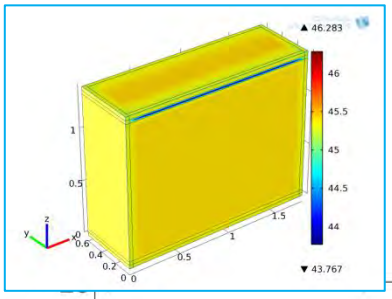


Test chamber experiment

- Sudden relative humidity increase from 50% to 70%
- Temperature is maintained constant at 20°C

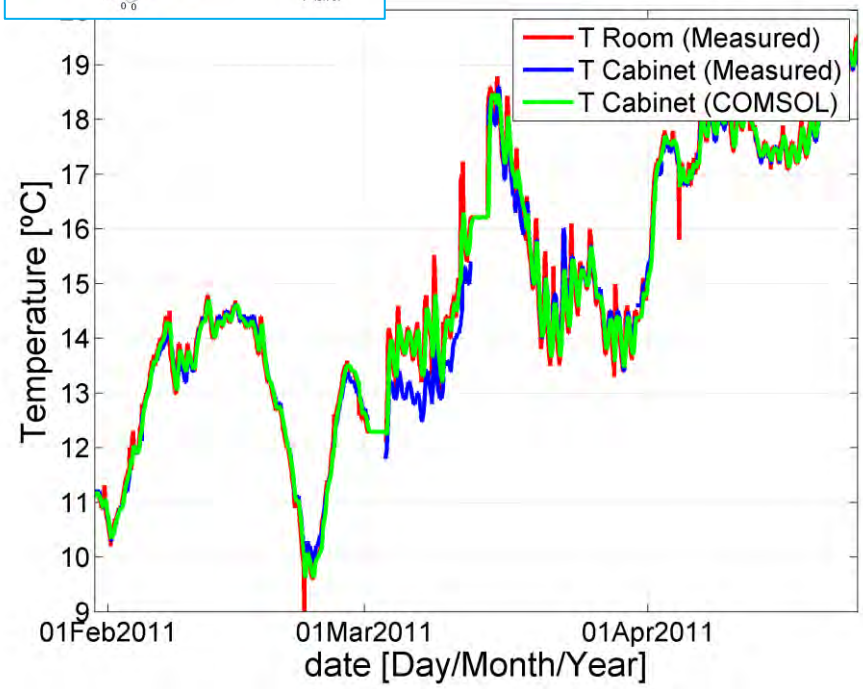


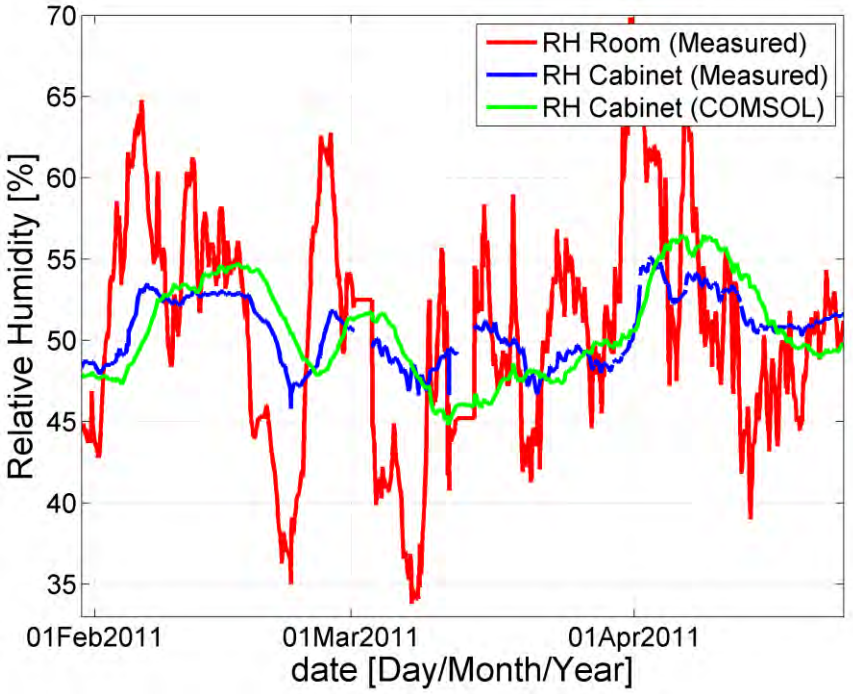
Microclimate conditions



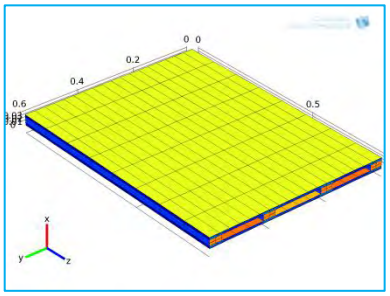
On-site measurements of temperature and relative humidity in Grand Salon and inside cabinet

- Comparison between measured and simulated microclimate conditions in COMSOL

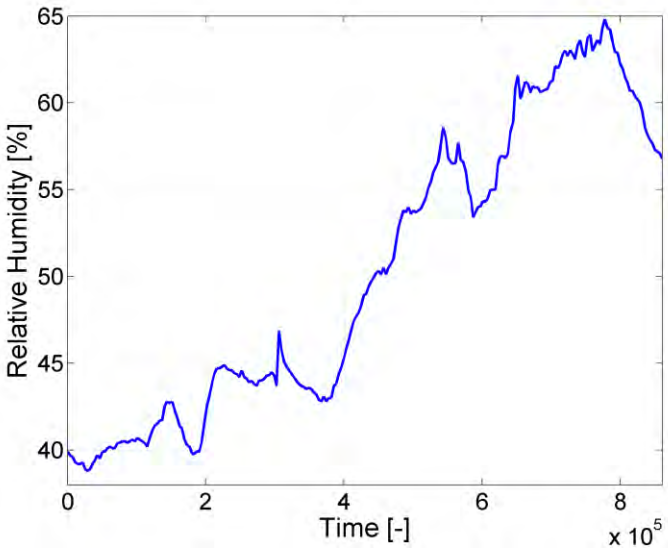




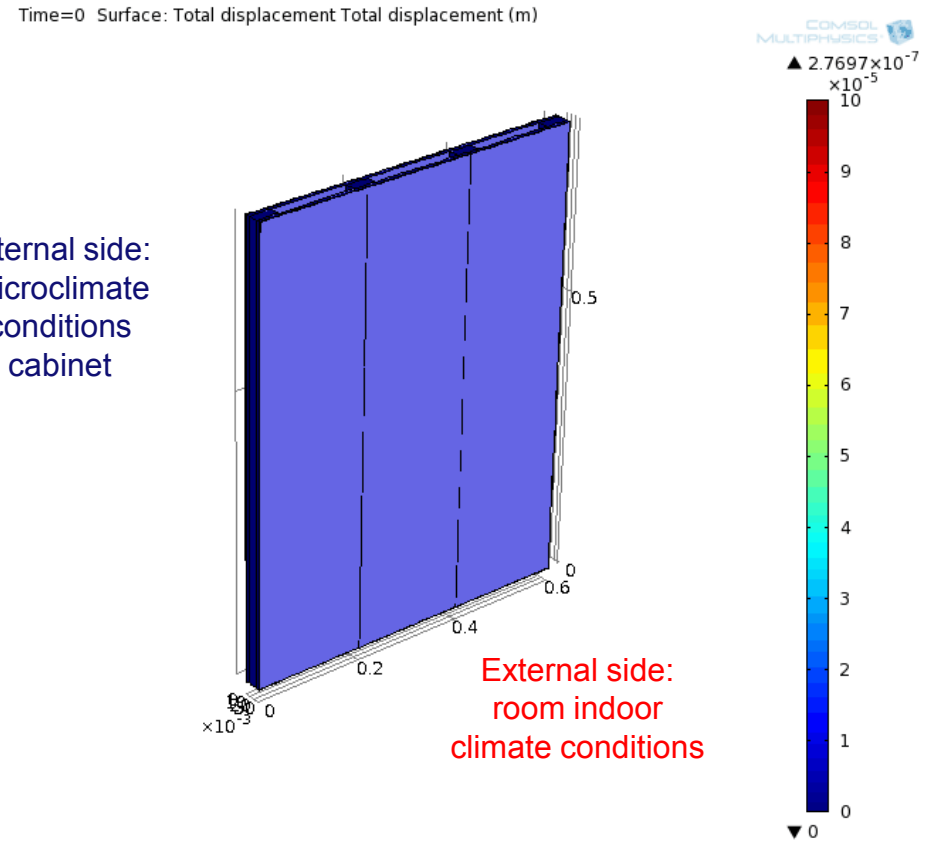
Deformation



Predicted displacement during 10 days

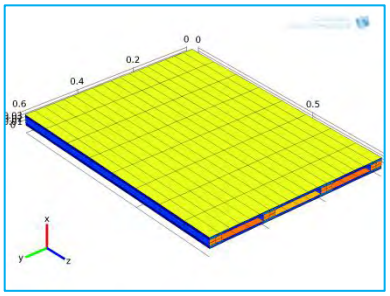


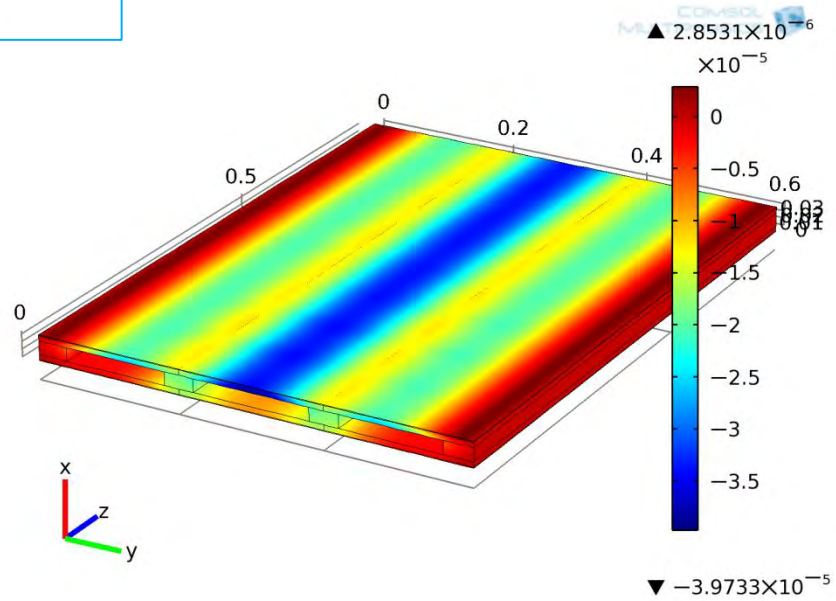
Internal side: microclimate conditions cabinet



External side: room indoor climate conditions

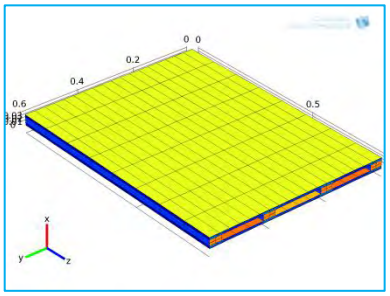
Deformation

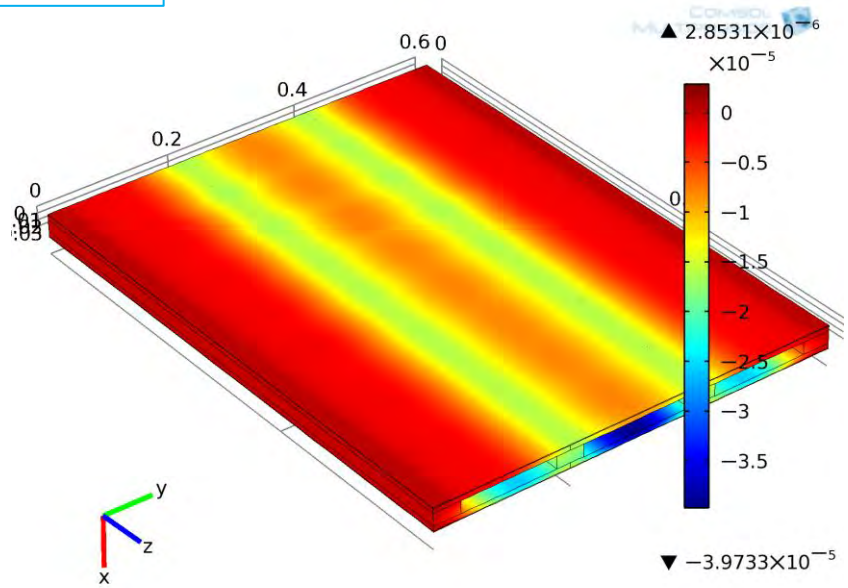




Predicted deformation at external side
t =1000

Deformation





Predicted deformation at internal side
t=1000

Conclusions

- **Response time of door panel is adequately predicted**
- **Modelling of microclimate conditions requires improvement**
- **Agreement is found between predicted deformation and visible damage**
- **More detailled measurements of hygroscopic and mechanical properties of the various wood types in the cabinet are necessary to calculate stress and strain in the cabinet as a result of climate variations**

Thank you for your attention

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