Moisture ingress into PV modules: long-term simulations and a new monitoring technique

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Goals and Motivations

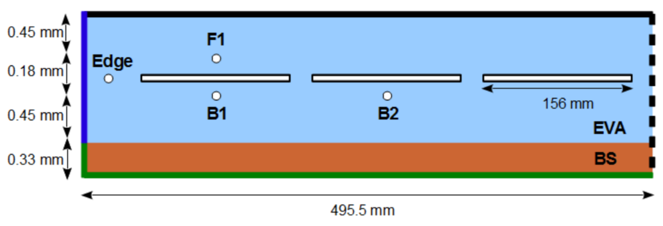
- **Predict moisture ingress into PV modules during long-term outdoor exposure, identifying impact of climate conditions and encapsulation scheme**
- **Improve modules life-time by better understanding water-related degradation mechanisms (e.g. delamination [1,2], potential induced degradation (PID) [3])**

Approaches

- **Water ingress is modeled with 2D Finite Elements Method (FEM) as a diffusion problem and simulated for:**
  - **three different climatic conditions**
  - **two different encapsulation schemes.**
- **A new monitoring technique is then employed to measure the relative humidity inside the PV modules and validate the simulation model.**

Water ingress modeling

Simulations model



- Water ingress in PV module materials described by Fick's Second Law of Diffusion:

$$\frac{\partial c(x,t)}{\partial t} = D(t)\frac{\partial^2 c(x,t)}{\partial x^2}$$

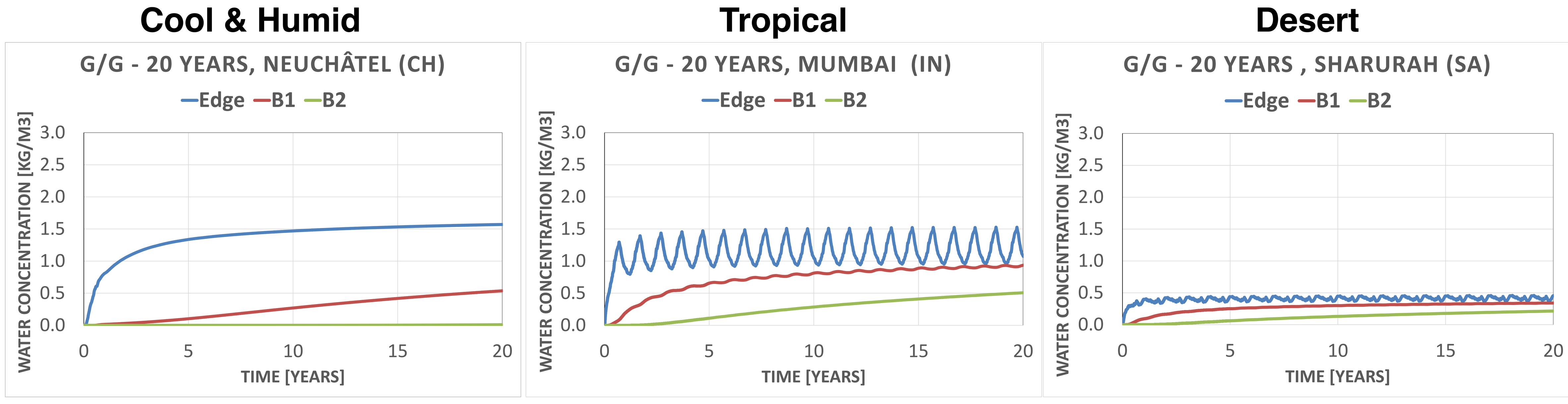
- Solved by FEM with experimentally determined water diffusion coefficient D and solubility S of EVA and backsheet
- Water concentration at the outer surface calculated with Henry's law:

$$c_{surf}(t) = S(t) \cdot p_{H_2O}(t)$$

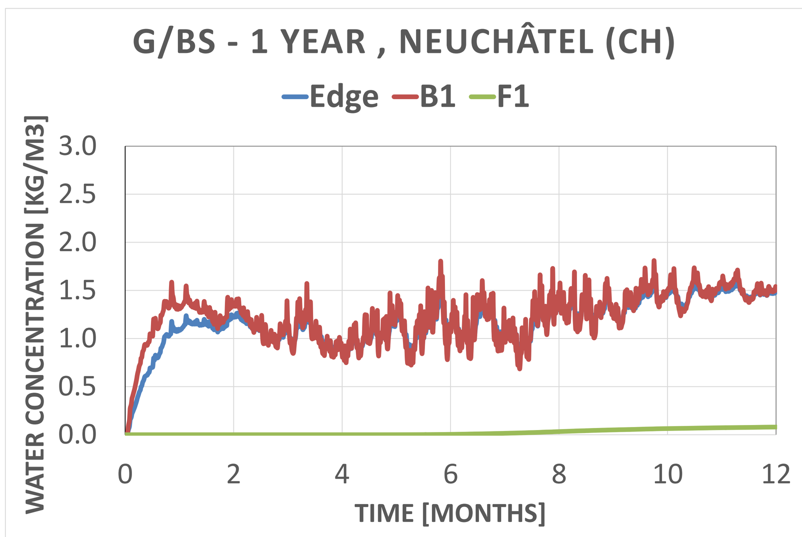
- 2-D geometry assuming infinite length in the 3rd dimension
- Symmetries (dotted lines) exploited to reduce computational times, with Glass/Glass (G/G) scheme also vertically symmetric
- Modules assumed initially dry
- Output: time-evolution of water concentration in different positions in the module (edge, front, back)

Glass/Glass: 3 climates, 20 yrs

Cool & Humid | **Tropical** | **Desert**



Glass/Backsheet: 1 climate, 1 yr

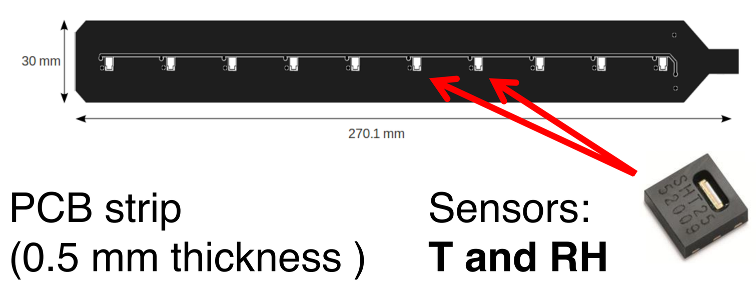


Observations

- As expected: fastest moisture ingress in tropical climate (high temperature and high relative humidity), with clear seasonal variations, particularly at the edge
- G/G reduces moisture accumulation with respect to G/BS (moisture content at cell back already larger in G/BS after 1st year than in G/G after 20 years).
- In G/BS, seasonal variations clearly visible at the cell back (increase in water concentration during cold and humid winter).
- G/BS simulations must now be extended to longer time-scales, such as in [4].

New monitoring technique: Encapsulated relative humidity sensors

Working principle



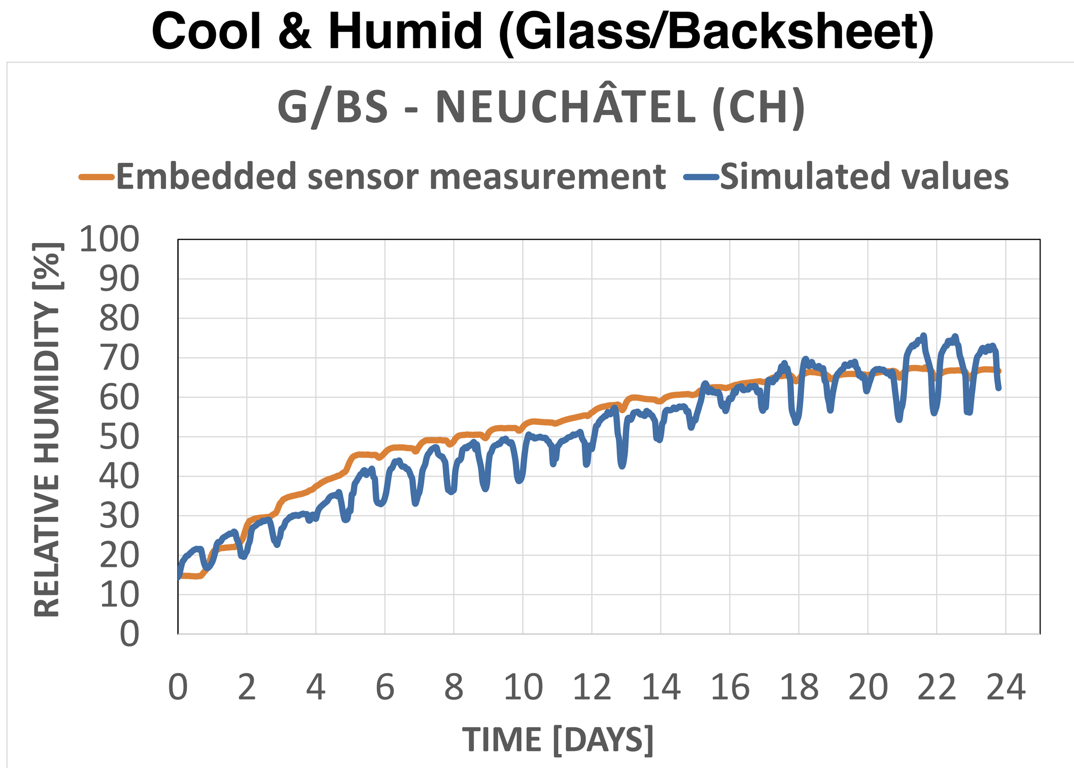
- Miniature digital relative humidity (RH) and temperature (T) sensors were soldered on a Printed Circuit Board (PCB) strip.
- The PCB strip was then laminated in G/G and G/BS samples.

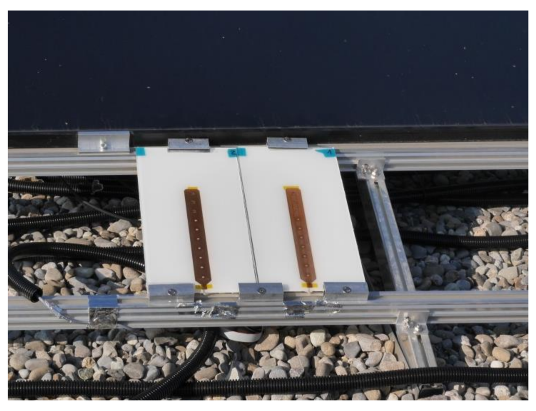
Measuring water concentration inside PV modules

- The technique has been preliminarily tested in climatic chamber
  → care must be taken when sensor operates outside its normal specified range
- Samples were then installed outdoor to track evolution of internal RH.

Simulations vs Measurements

Cool & Humid (Glass/Backsheet)





Time-evolution of RH inside a G/BS sample in outdoor conditions (cool & humid climate) as measured by a sensor and simulated by FEM

First results: Good agreement between measurement and simulation

Conclusions/Outlook

- ***Water concentration inside PV modules was simulated for different climates and encapsulation schemes:***
  - ***As expected, tropical climate induces fastest water ingress, however cool & humid climate also features high water content after 20 years***
  - ***G/BS after 1 year already shows higher water content than G/G after 20 years***
- ***For G/BS, good agreement between simulated results and outdoor monitoring. But further (ongoing) experiments required, also in climatic chambers.***
- ***Optimized choice for encapsulant materials, and in-depth investigation of moisture-related failure modes (e.g. delamination, PID) can be performed based on this analysis.***

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[4] P. Hülsmann et al., "Simulation of Water Vapor Ingress into PV-Modules under Different Climatic Conditions", Journal of Materials, Volume 2013

Acknowledgments

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