Impact of Hygrothermal Behavior on Optimal Requirements and Testing

CEEES Seminar 26.9.2008

"Management of Verified Environmental Stresses"

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Outline

- **Background and Objectives**
- **Theoretical response models**
  - Temperature and Humidity
- **Semi-empirical response model**
  - Takes into account absorption and desorption of water to materials
- **Requirement and test optimization**
  - Device characteristics
  - Usage environment
  - Device response
  - Optimal test
- **Conclusions**

Background and Objectives

Drivers / Motivation:

- Cost saving through optimal requirements and that way optimal design
- Cost saving through optimal testing, maximal acceleration (minimal test time) and effective finding or relevant failures in tests

Background:

- Packaging of outdoor electronics in Hot and humid environments
- Mechanics and materials of device effect on in-device environment and transients – i.e. in-device stresses
- Hygro-thermal response of device has to be know for ensuring optimal environmental requirement and test procedure

Objectives

- To study experimentally device responses for T and Humidity
- To analyze effect findings on internal conditions of device in real usage
- To conclude potential impact of findings on environmental requirements and testing

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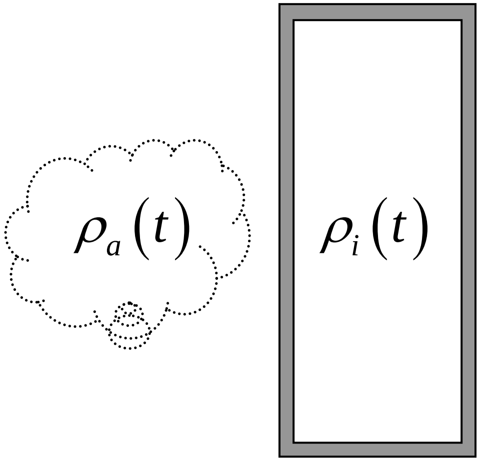
Theoretical response models:
Hygrothermal Model

Step change in vapour density i.e. humidity concentration, constant temperature

Fick's Second Law

Quasi- steady-state approximation*

$$\frac{\partial \rho_i(t)}{\partial t} = \frac{1}{\tau_C}\left(\rho_i(t) - \rho_a(t)\right)$$



For a step change:

$$\rho_i(t) = \rho_a - (\rho_a - \rho_i^{\,0})\exp(-t/\tau_C)$$

Characteristic parameter is Mass transfer time constant, τ_C

* Tencer, M., 1994, "Moisture Ingress into Nonhermetic Enclosures and Packages: A Quasi-Steady State Model for Diffusion and Attenuation of Ambient Humidity Variations", Proc. 44th ECTC, pp. 196-209.

Theoretical response models:
Hygrothermal Model

Mass transfer time constant, t_C

Function of:

- Enclosure volume, V • Surface area, A • Wall thickness, L
- Permeability, P
- Diffusion coefficient, D

$$\tau_C = VL/AP + L^2/2D$$

- Thin, non absorbing walls;
- Enclosure volume >> wall volume

→ Permeability is critical

- Thick, absorbing walls;
- Wall volume > enclosure volume

→ Diffusion coefficient is critical

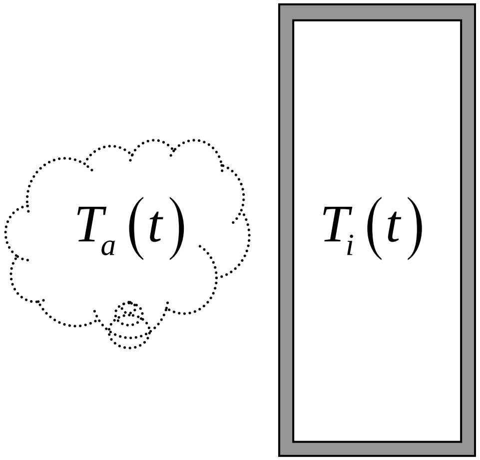
Theoretical response models:
Hygrothermal Model

Step change in temperature, constant vapour density

One-dimensional, transient heat transfer

Lumped-capacity approximation, for a step change:

$$T_i(t) = T_a - (T_a - T_i^0)\exp(-t/\tau_T)$$



Thermal time constant, τ_T

$$\tau_T = R_{th} C_{th}$$

Where

- R_{th} = thermal resistance
- C_{th} = thermal capacitance

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Analysis:
Hygrothermal Model

Temperature rise, constant ρ

Time 0 → **equilibrium**

Period 1 → **Desorption of moisture** from hygroscopic materials

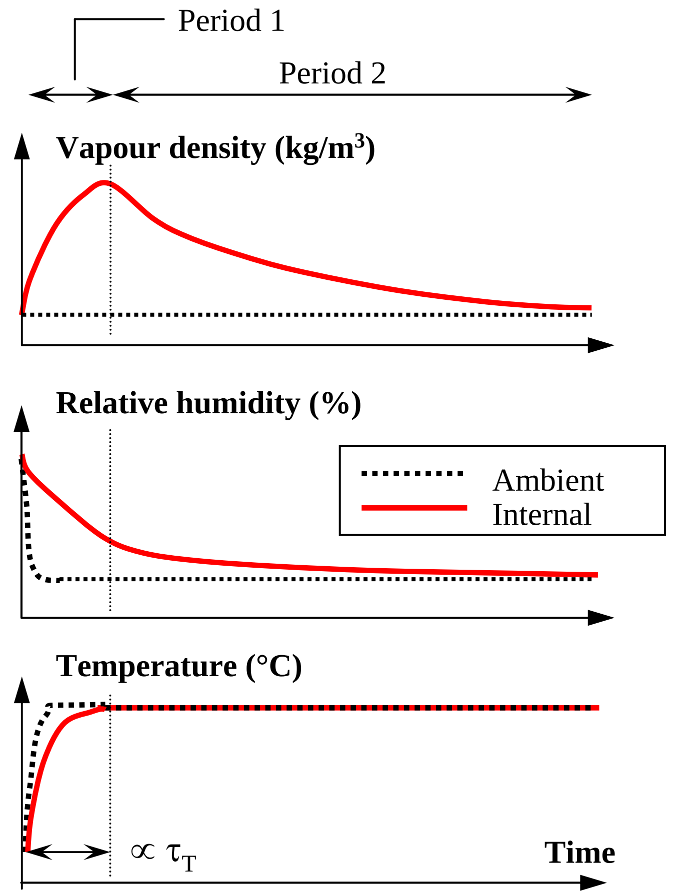
Period 2 → **Thermal equilibrium**, mass transfer to ambient

Semi-empirical form*:

kgK/m³ s

$$\frac{\partial \rho_i(t)}{\partial t} = \frac{1}{\tau_C}\left(\rho_i(t) - \rho_a(t)\right) - C^*\left(\frac{1}{T_i(t)} - \frac{1}{T_a(t)}\right)$$

In general, significance of semi-empirical term increases when V<<A



* Punch, J., Grimes, R., Heaslip, G., Galkin, T., Väkeväinen, K., Kyyhkynen, V. and Elonen, E., 2005, "Transient Hygrothermal Behaviour of Portable Electronics", IEEE EuroSIME 2005: Thermal, Mechanical and Multi-physics Simulation and Experiments in Micro-electronics and Micro-systems, pp. 398-405.

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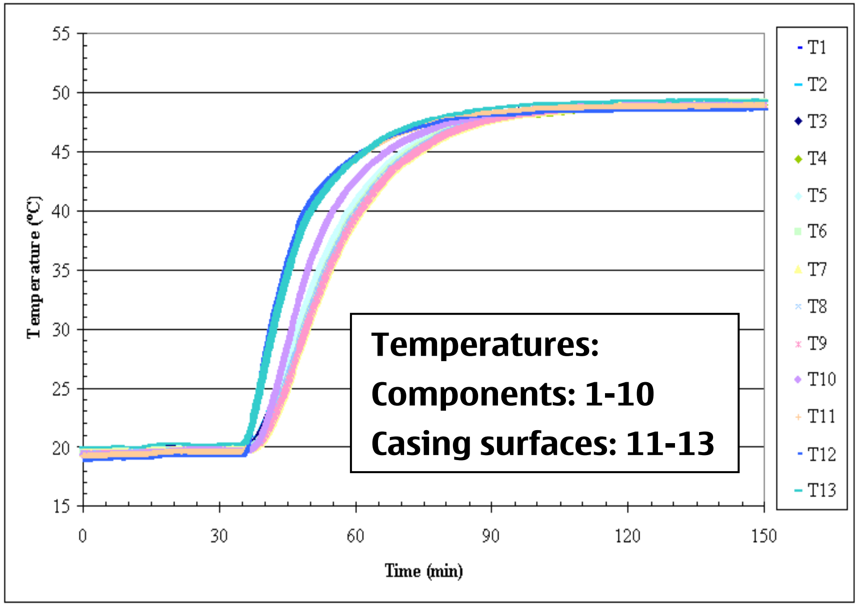
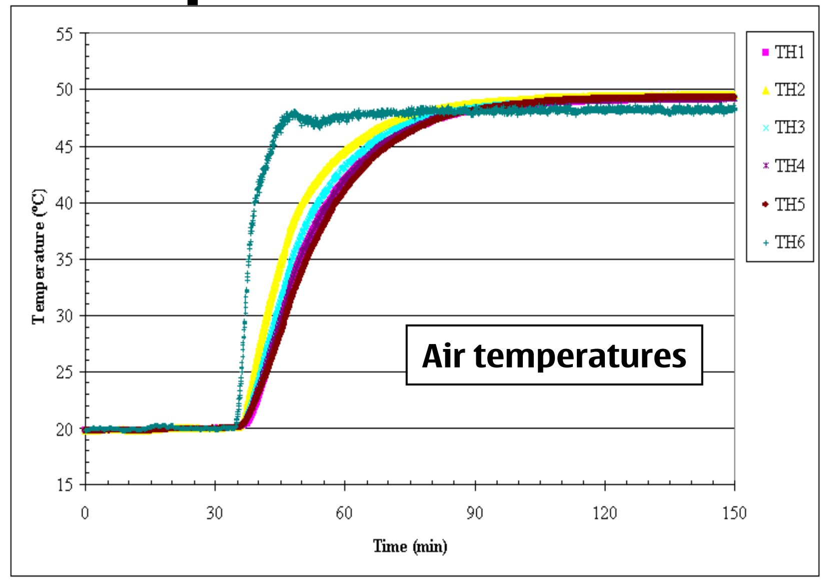
Procedure for optimal Temperature & Humidity requirement and testing

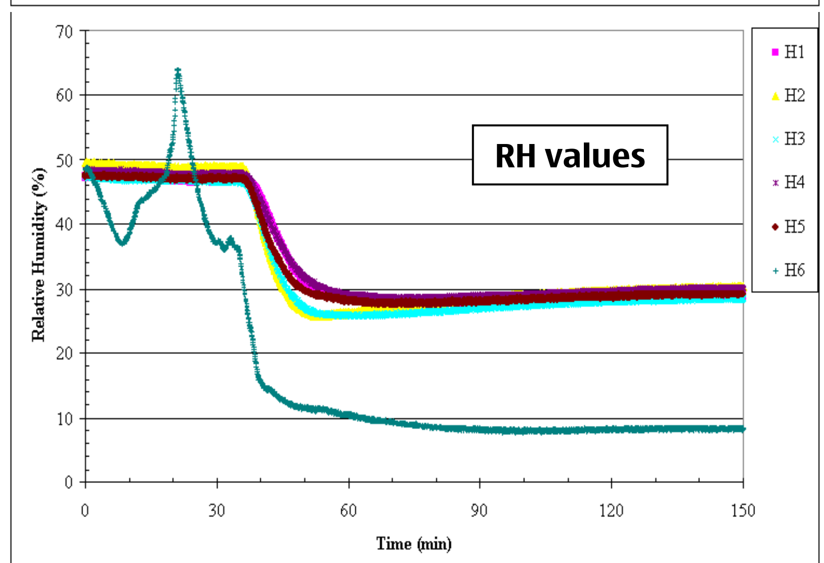
1. Device characteristics
   - Time constant for Temperature
   - Time constant for Humidity
   - Absorption and desorption considered
2. Usage environment
   - Meteorological data analysis
   - Events, which can effect on internal environment
3. Device response
   - Response models
   - Input data: Experimental time constants and meteorological data
   - Effect of events → experimentally
4. Optimal requirement and test
   - Requirements from device responses
   - Test for replicate in-device stresses in field

* Punch, J., Galkin, T., Ojala K., Rodgers, B., 2006 "The Hygrothermal Behaviour of Outdoor Electronic Equipment in Time-Varying Hot and Humid Weather Conditions", IEEE ASTR 2006: Workshop on Accelerated Stress Testing & Reliability

Optimal environmental test
1. Device characteristics – Temperature



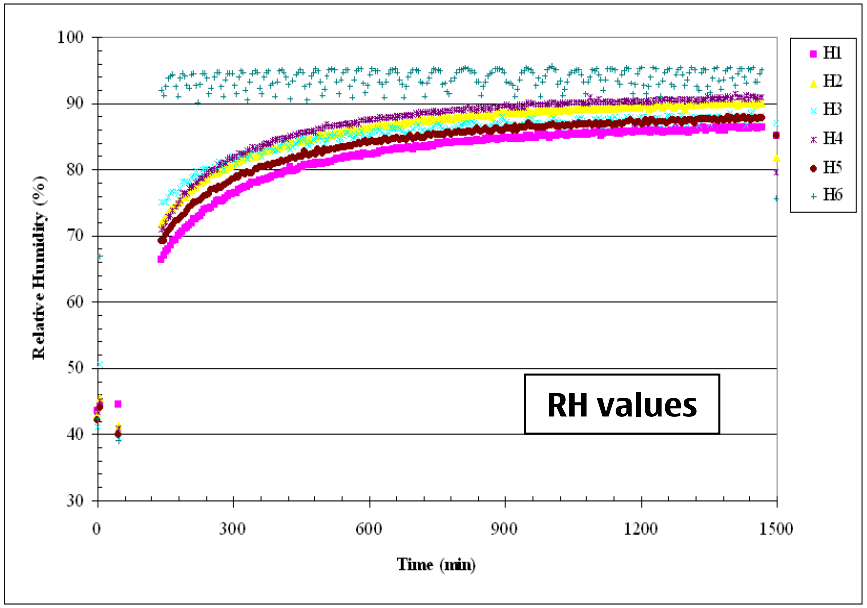




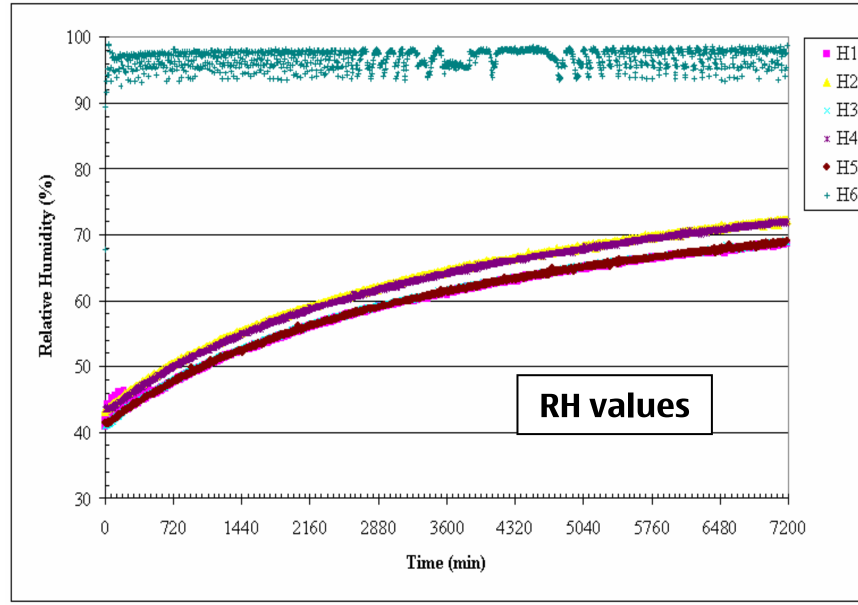
- T-step 20→50°C: Unit in chamber at ambient RH (40%), apart from 'spike' at ~20min
- **Thermal time constants (minutes):**
  - **Components: <u>17.09–19.92 (Mean 18.55)</u>**
  - **Air temps.: <u>16.50-18.25 (Mean 17.60)</u>**
  - **Initial thermal constants for components**
- **Stabilisation time ≈ 54 minutes**

IMPACT ON TEST: Optimal Dwell Times

Optimal environmental test
1. Device characteristics – Humidity



Aperture Open



Aperture Closed

- In each case, the Unit was started at nominal 20°C, 40%RH
    - Step to 20°C, 90%RH
- **Humidity time constant (hours):**
    - **Aperture Open: 10.72–20.28 (Mean 15.75 → 0.66 days)**
    - **Aperture Closed: 163.93–185.19 (Mean 175.34 → 7.31 days)**

IMPACT ON TEST: Time constant has to be considered in in-device humidification

Optimal environmental test
2. Usage environment

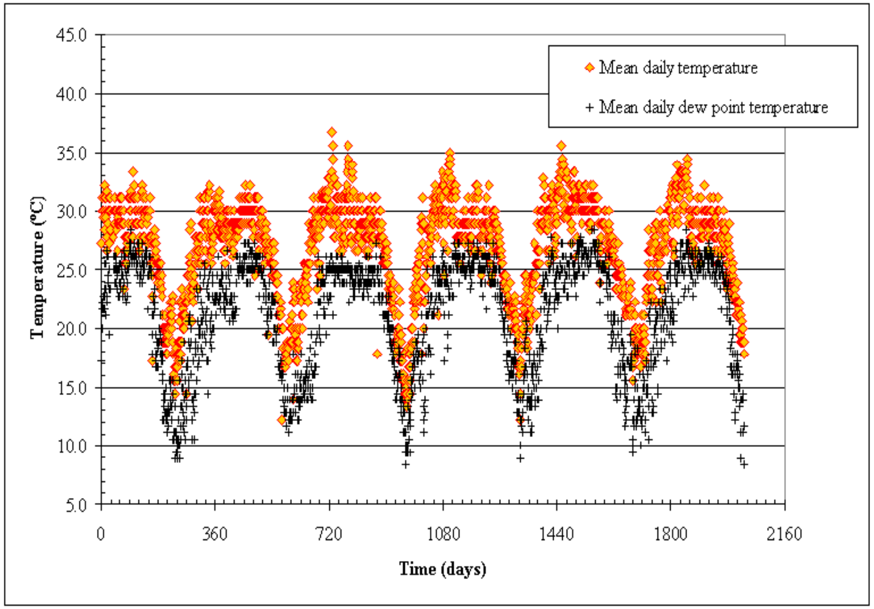
Meteorological data: T & RH

Reference environment 1:

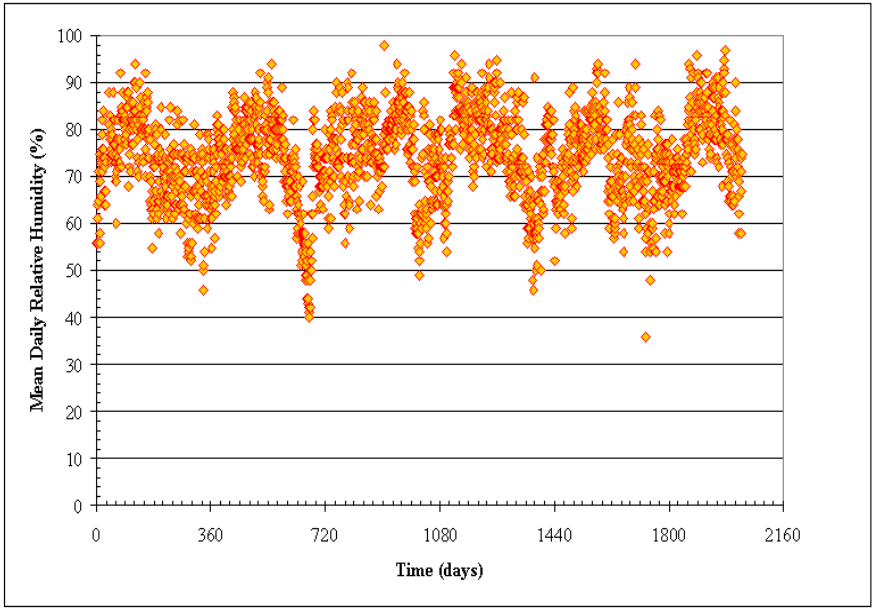
– Warm temperature, Hot summer (Heavy rain fall events: Annual mean 69), Dry winter

Over 5 years (2000 – 2005) climatic data

IMPACT ON TEST & REQ.: T(max), T(min), annual humidity cycles



Mean daily values of temperature and dew point temperature



Mean daily values of relative humidity

Average daily level of relative humidity: 74.3%

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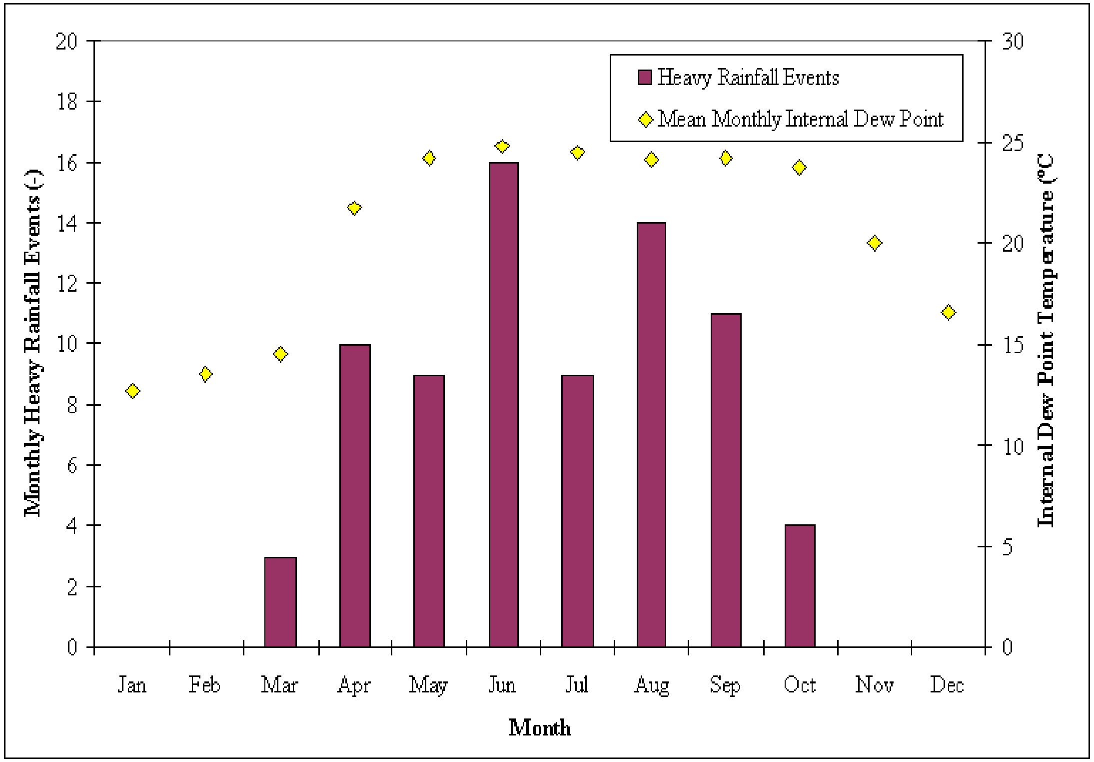
Optimal environmental test
2. Usage environment – Events

Most of rainfalls in high humidity season → High Risk of Condensation



Monthly numbers of heavy rainfall events and predicted mean monthly internal dew point temperature

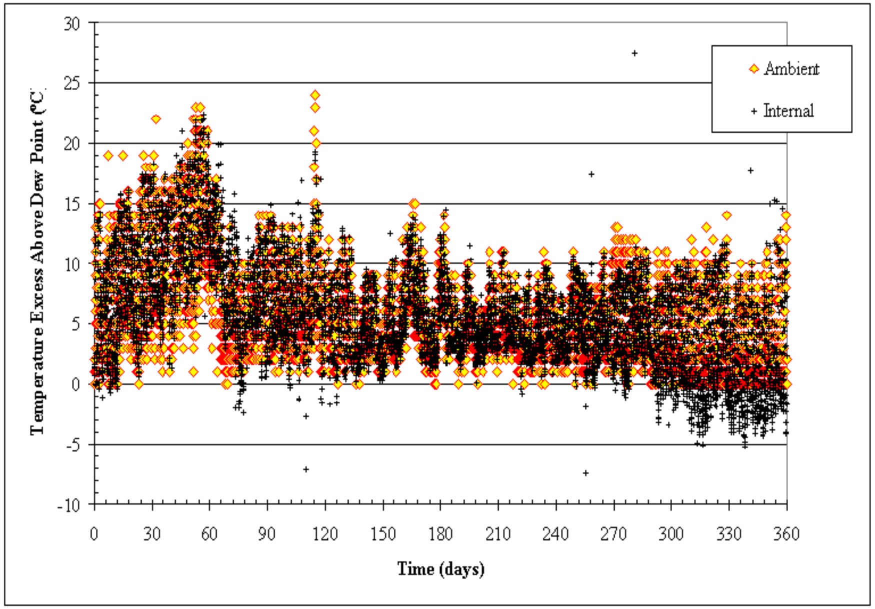
Optimal environmental test

3. Device Response – In-device conditions

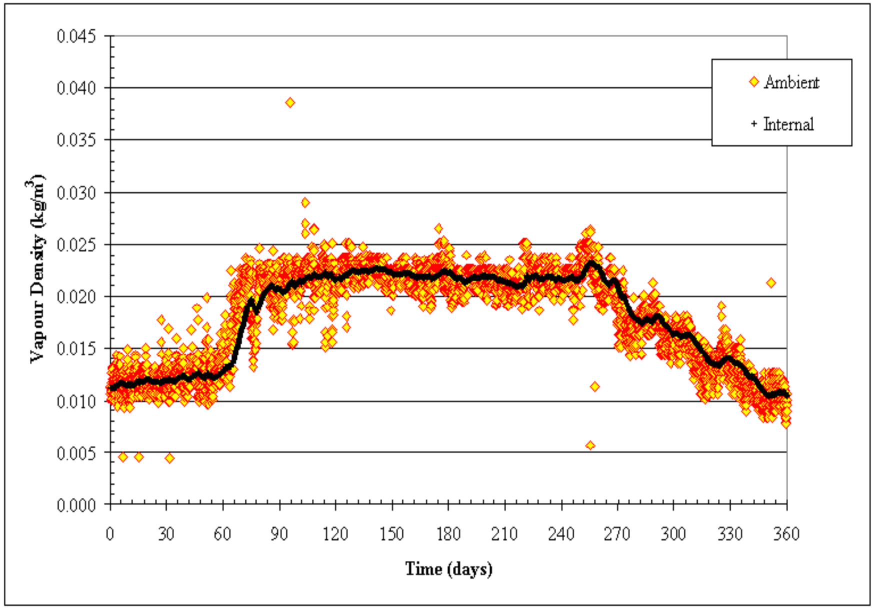
Meteorological Data – Reference environment 1

Vapour density response is damped

IMPACT ON TEST & REQ.: Long humid period → humidity gets into device



Predicted temperature excess above dew point



Predicted vapour density response
→ **<u>Note:</u>** 200 days high water vapour density period → time enough for humidity diffuse into device

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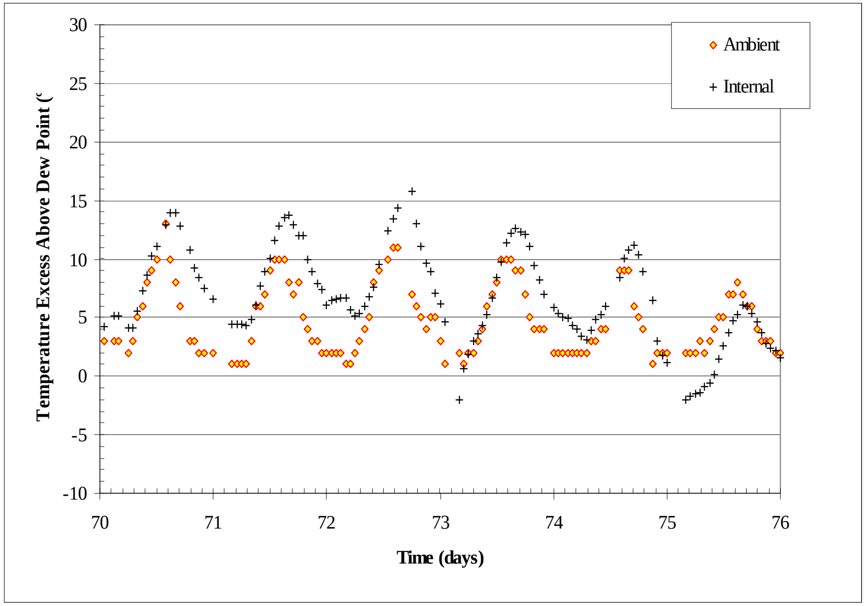
Optimal environmental test
3. Device response – Ramp rates

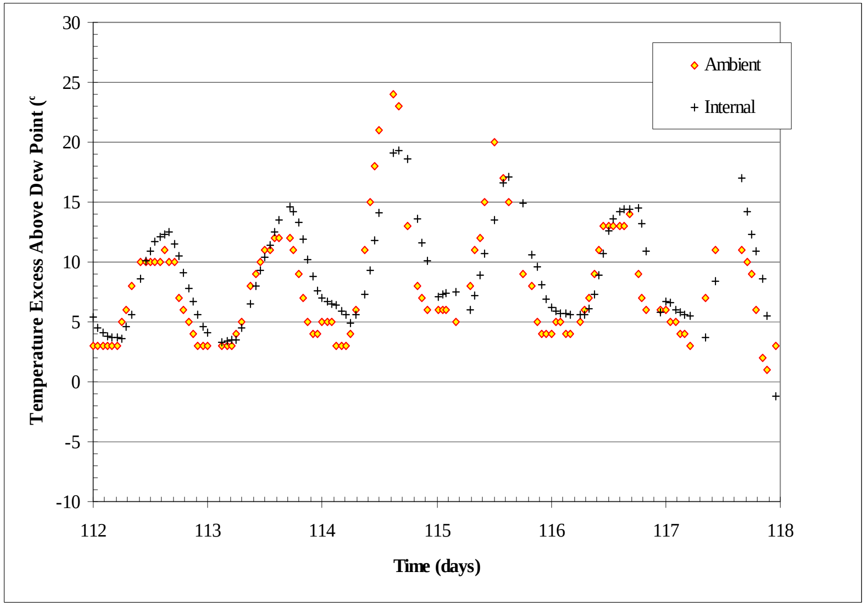
Meteorological Data – Reference environment 1

Predicted temperature excess above dew point

6 day data excerpts

IMPACT ON TEST: Real ramp rates of T in device and components





Vapor density ramp-up period

High vapor density period

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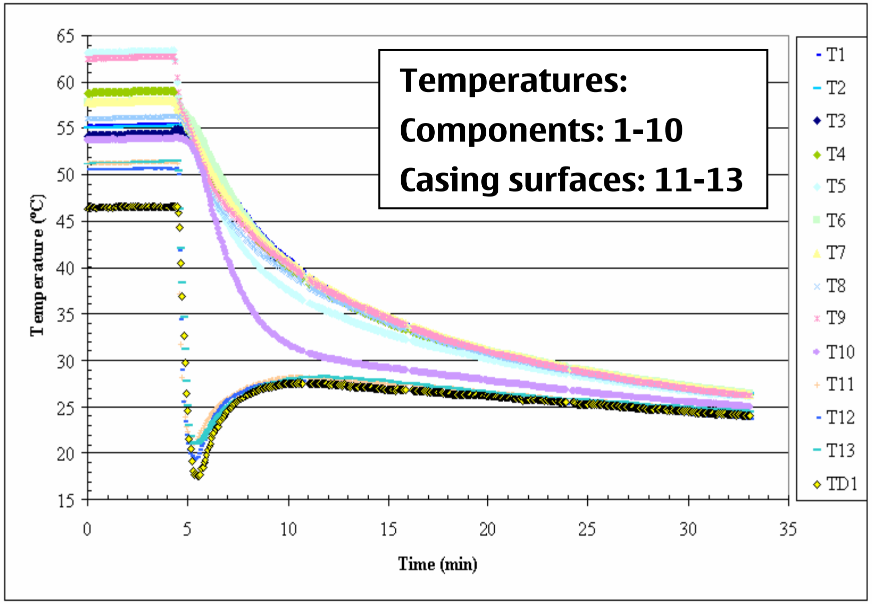
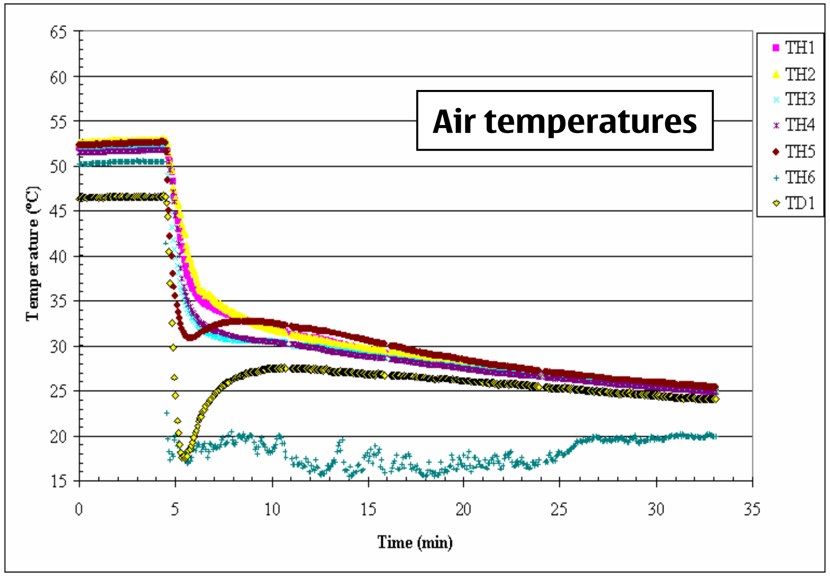
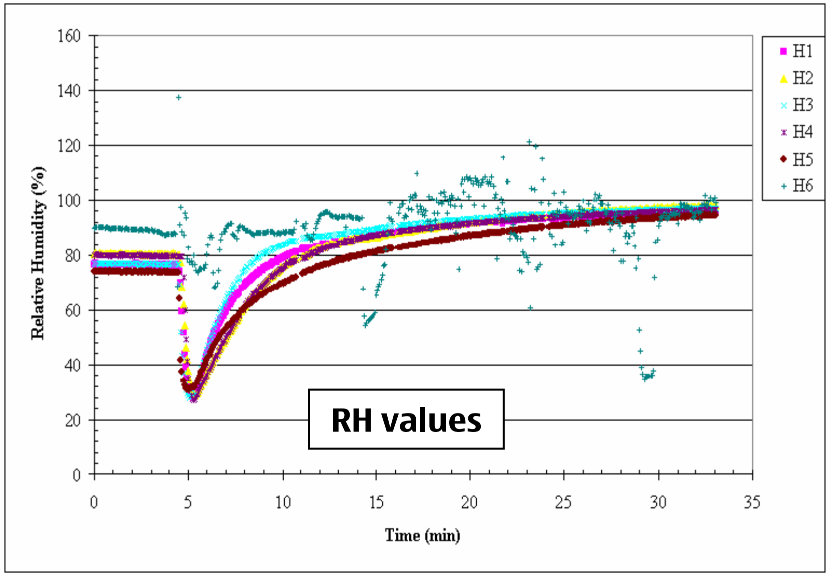
Optimal environmental test
3. Device response – Events / Rainfall







- Unit stable at 50°C, 72-80%RH, *Power On*
- Simultaneously: *Power Off*, open chamber and apply ‘rain’ at 18.1°C for 1 min
- Sensor data indication → Drop in internal RH is evidence of moisture condensing

IMPACT ON TEST & REQ.: Rainfall can evidently induce condensation

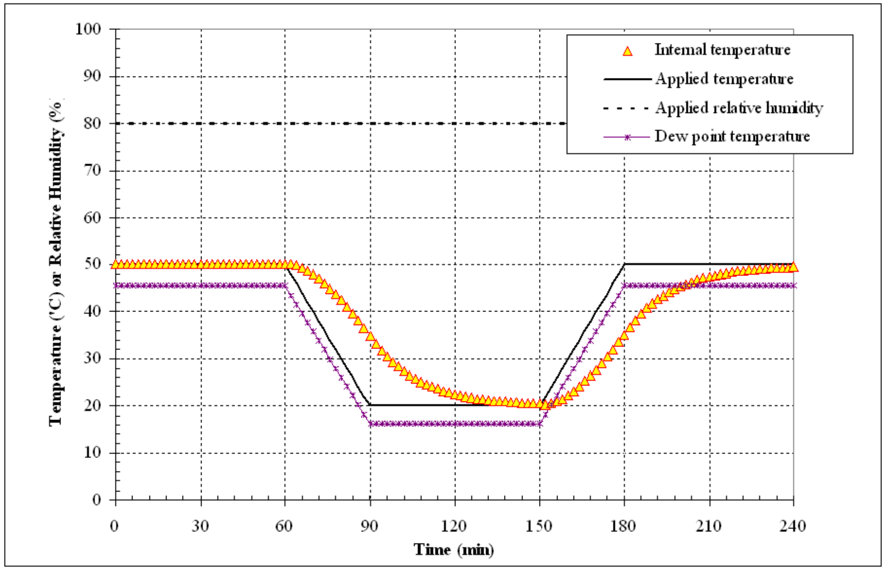
Optimal environmental test

4. Optimal test – Numerical simulation

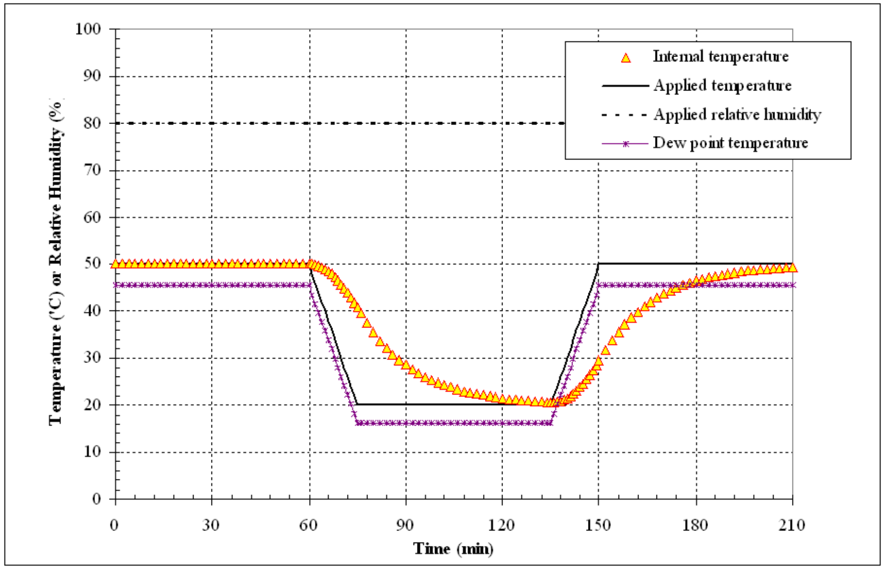
Condensation Test

Predicted Hygrothermal Response

'Pre-humidified' Unit (50°C, 80%RH)



Response to condensation test with 1°C/min ramp rates, 50°C to 20°C limits.

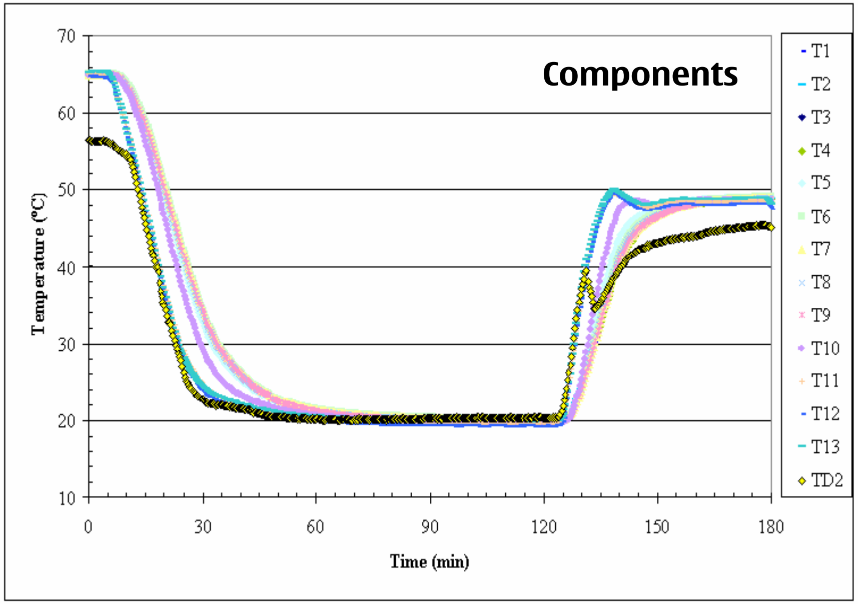


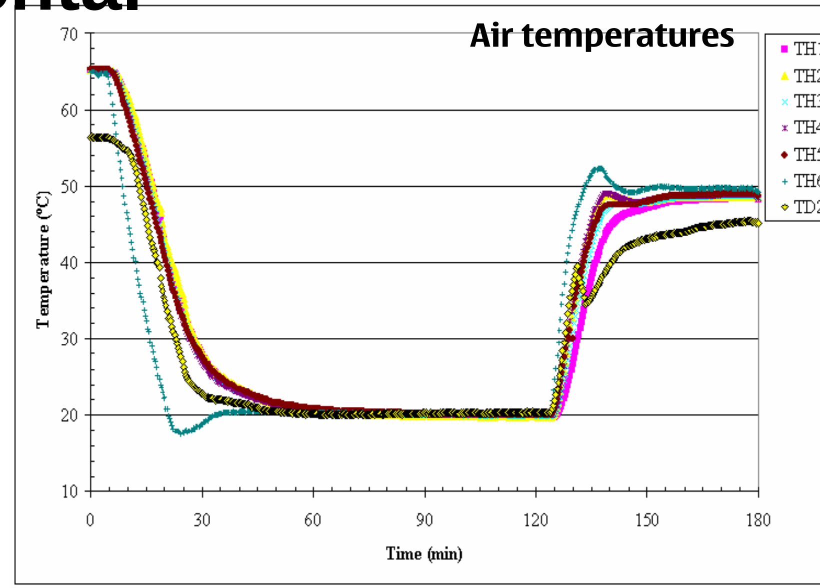
Response to condensation test with 2°C/min ramp rates, 50°C to 20°C limits.

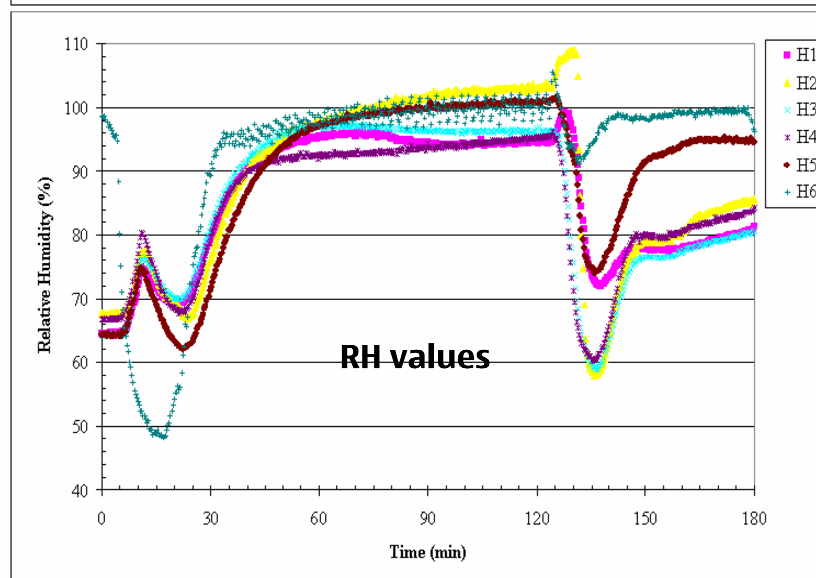
A minimum dwell time at low temperature is required in order to induce condensation

Optimal environmental test

4. Optimal test – Experimental







- Unit ‘pre-humidified’ to 65°C, 64-68%RH
- 65°C→20°C→50°C in steps
- Constant set-point 95%RH
- Highest dew point (TD2) shown on temperature plots to indicates – is evident of - possibility of condensation
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Conclusions

- Temperature and humidity requirements optimization procedure was introduced
- Response models, device characteristics and climatic data can be combined for requirement and test optimization by following procedure
    1. Measure device responses
    2. Calculate time constants (T & Humidity) from measurement data
    3. Analyze climatic data
    4. Calculate, pilot test and conclude general and worst cases in-device stresses
    5. Conclude effects of findings on requirements
    6. Optimize test procedure so that all the relevant stresses are included
- Requirement and test optimization enable cost reduction
- Ultimate target is to create device design optimization guidelines for use environment - optimized requirements and tests are enablers for that

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THANK YOU!

Questions or Comments?

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