The Ageing Effects of Vacuum Insulation Panels (VIPs) on the Long Term Thermal Performance of a Building Envelope with the use of Dynamic Simulation Tools

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Background

- Vacuum insulation panels (VIPs) → new **high performance thermal insulation**
- **High thermal resistance** with **very low thickness**
- **High thermal resistance due to the vacuum inside the panels**. The absence of gas molecules able to transfer heat energy by bulk movement through the insulator, minimizes convection losses. It also greatly reduces conduction, as there are far fewer collisions between adjacent gas molecules (or between gas molecules and atoms of the core material)
- **Gradual increase** with time **of the initially low internal pressure and moisture content** of the panel leads to **deterioration of it's thermal resistance**

VIPMODE CODE: VIP degradation modelling

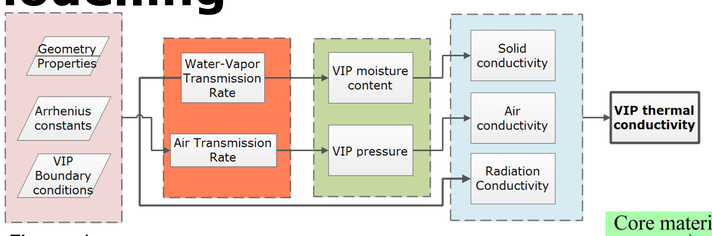


Figure 1

- $\lambda_{eq} = \lambda_c + \lambda_s + \lambda_g + \lambda_r$
- **Dynamic temperature** and humidity boundary conditions
- **Temperature dependent** membrane transmission properties (Arrhenius equation)
- Separation of **Surface** and **perimeter** gas transmission through the membrane

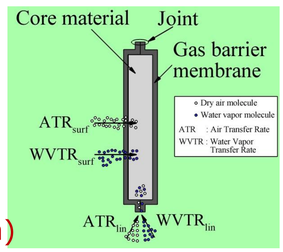


Figure 2

Dynamic building simulation

- VIPMODE code requires **temperature and humidity input** from a **TRNSYS simulation** for each yearly iteration.
  - Temperature/humidity data required **at both surfaces** of the VIPs (red and green point in Figure 3a).
  - Normally not available in TRNSYS (inside the element)
    →two **fictive zones** have been defined **per orientation**. (Figure 3b).

Fictive Zones

- Practically no volume and capacitance
- Inside-surfaces : very high convective heat transfer coefficient
  - the surfaces on both sides of each fictive zone, perform as adjacent surfaces. (temperatures in the red points and in the green points (Figure 3b) are identical).
- **8 fictive zones (2 per orientation)**

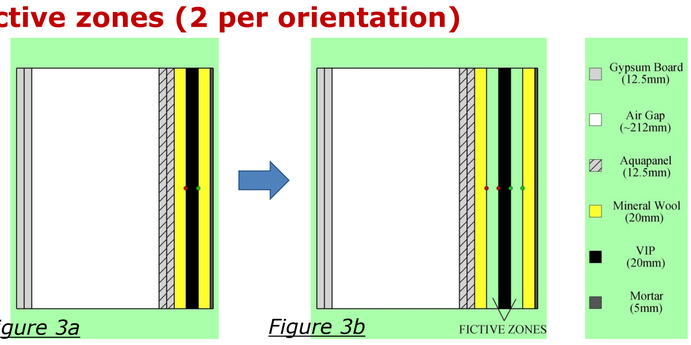


Figure 3a *Figure 3b*

VIPMODE and Dynamic Building Simulation coupling

The in-house algorithm **VIPMODE** was **coupled** (Figure 4) with a dynamic building simulation tool (**TRNSYS 17**) in order to evaluate the consequences of the thermal conductivity deterioration in the buildings thermal demand during its lifetime.

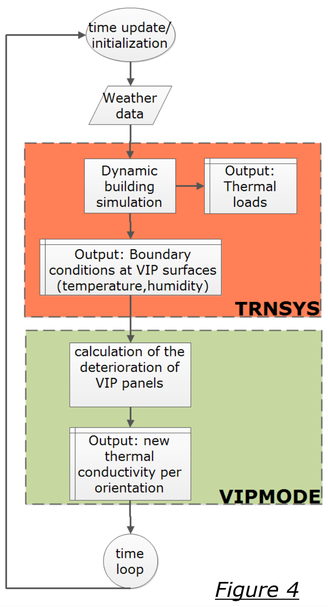


Figure 4

Parameters

- **Each orientation is treated separately**
- **1 year interval** was chosen for the thermal conductivity of the walls to be altered in the TRNSYS simulation. (yearly increase <0.2 mW/mK)
- Combined **simulation**: **50 years (building's lifetime)**
- **Repetitive weather pattern**

Results

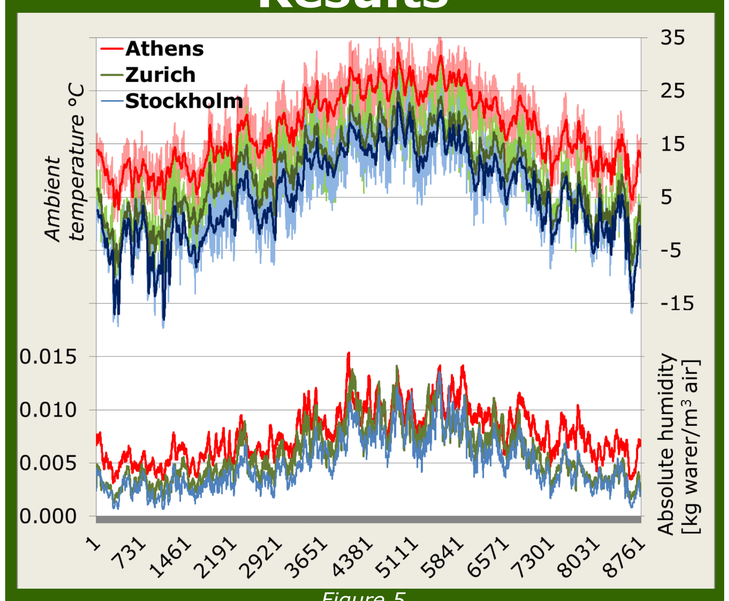


Figure 5

Up: Ambient air temperature and average daily temperature at the 3 examined cities
Down: Absolute humidity at the 3 examined cities

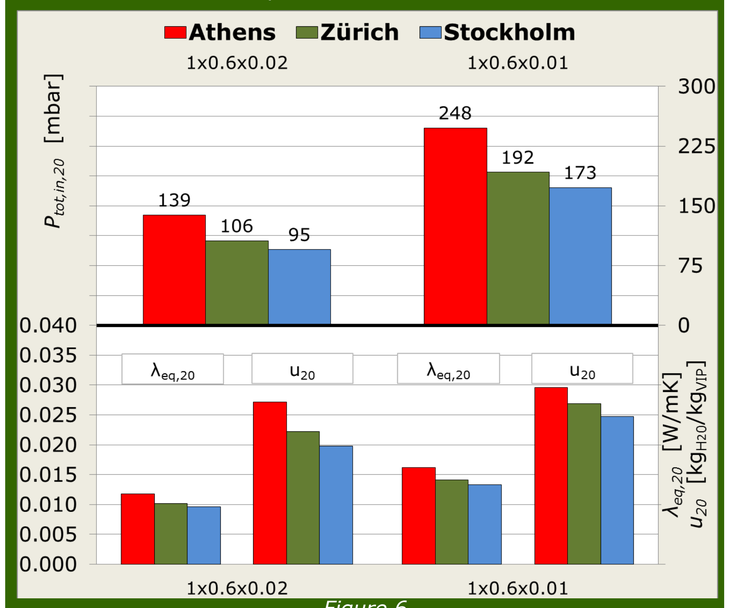


Figure 6

Up: Vapour pressure for two panel sizes after 50years in each location.
Down: Thermal conductivity and water content in the VIPs after 50years for two panel sizes.

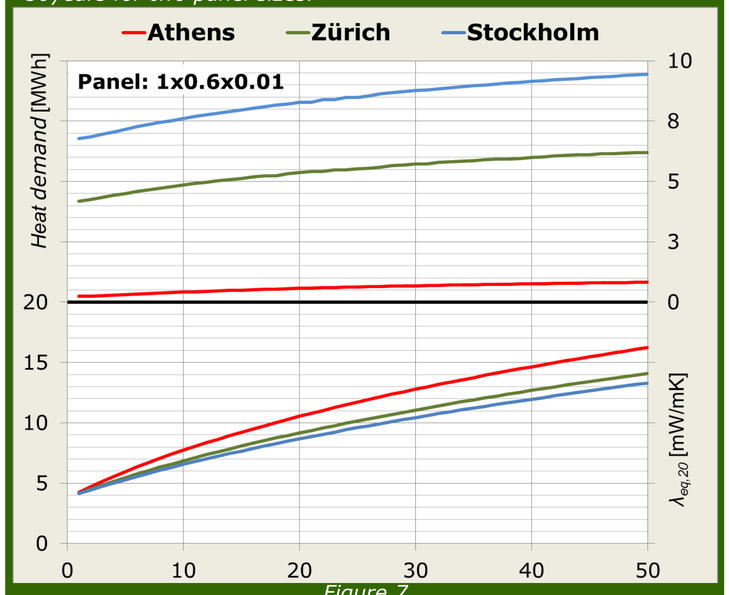


Figure 7

Up: Thermal demand evolution in the 3 examined climatic regions.
Down: Thermal conductivity evolution over the buildings lifetime

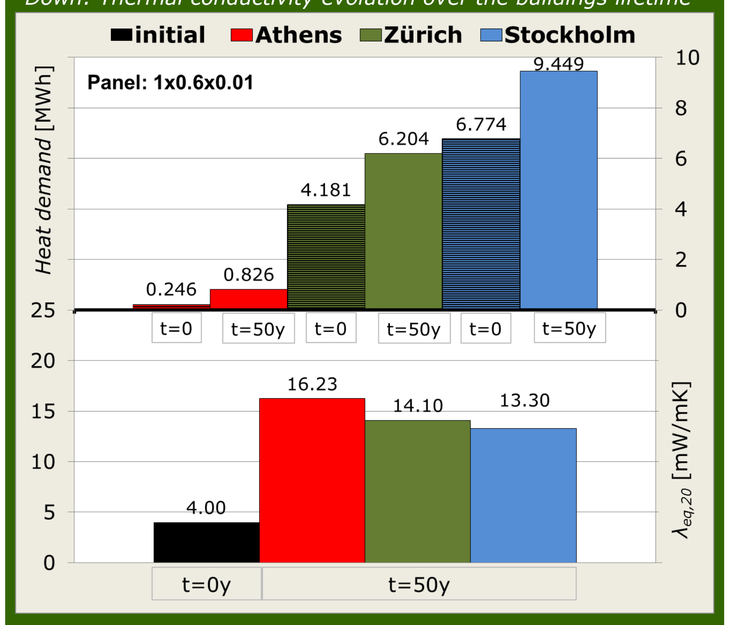
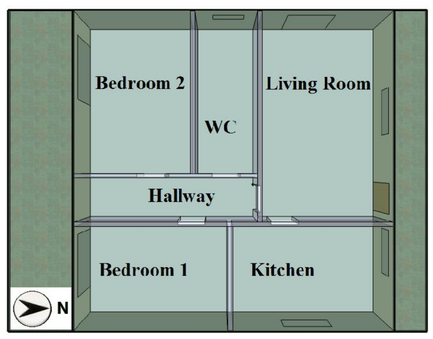


Figure 8

Heat demand (Up) and thermal conductivity (Down) ; initially and after 50years at the 3 examined locations.

The House

- Simulated apartment (Figure 9): **99.6m² floor area.**
- **"Middle" floor** of a **multi-storey building**
  - Utilization of **adiabatic boundary conditions** on the upper and lower boundaries
  - Focus on the insulating properties of the external walls.



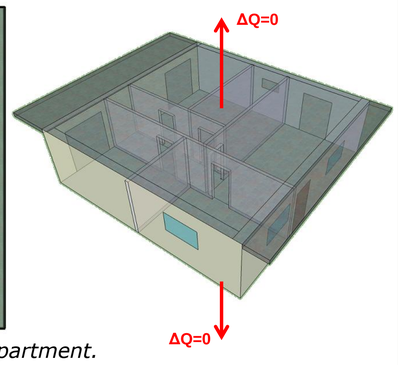


Figure 9: Geometry of the examined apartment.

Simulation Cases

- **Three** different **European regions** examined with **different climatic conditions**:
  - **Athens** (Köppen Classification: **Csa** subtropical Mediterranean climate)
  - **Zürich** (Köppen Classification: **Cfb/Dfb** oceanic or humid continental climate)
  - **Stockholm** (Köppen Classification: **Dfb** humid continental climate)

- **VIPs** come with **different sizes** in order to effectively cover facades with different geometry **and various thicknesses** to achieve different λ-values.
  - Different size or thickness leads to **different area** and **perimeter**.
  - **Water vapour and air transmission rates** depend on area and perimeter
    →Different panel sizes lead to **different aging rates**
    →Insulating performance **deteriorates** at a **different rate**

Two **panel sizes** were investigated:
- **1m x 0.6m x 0.02m**
- **1m x 0.6m x 0.01m**

Results

Climatic effect (Figure 7 and 8):

- **Significant variation** in thermal conductivity for the examined cities, **(λeq,20)** after **50years**:
  - Zürich 14 mW/mK
  - Stockholm 13 mW/mK
  - Athens: **16 mW/mK** (**worst scenario**)
    Four times increase of thermal conductivity

- Corresponding variations in annual **heat demand:**
  - **Zürich** and **Stockholm 140-150% increase**
  - **Athens increases** up to more than **3 times** its initial value

Panel thickness effect (Fig. 6):

- **Double** thickness → **3 times better** final values of **thermal resistance,** as total pressure and moisture accumulation per kg of panel is significantly reduced.

Conclusions

✓ The study of VIPs with the use of **dynamic simulation algorithms** is a **valuable tool** providing insight of the **behavior** of the **panels with different characteristics under various climatic conditions** during their service life.

✓ Findings of the current work suggest that **climatic conditions and panel size, amongst other, can be a major factor affecting the lifetime of VIPs** and are critical issues that need to be addressed during the design of insulation systems for building envelops.

The authors acknowledge the financial support of the European Commission in the frame of the FP7 NMP projects "FC-DISTRICT" and "ELISSA".