LARES

UNIVERSITY OF ZAGREB
Faculty of Electrical Engineering and Computing

Optimizing Insulation Thickness for Energy and Cost Efficiency in Residential Buildings: A Case Study

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Why Smart Buildings & Better Insulation Matter?

- **We want to live sustainably!** There's a growing demand for homes that save energy and protect our planet

- **Buildings are huge energy consumers!** The building sector is one of the highest energy consumers in Europe

- Two main ways for a home to become "energy-smart":

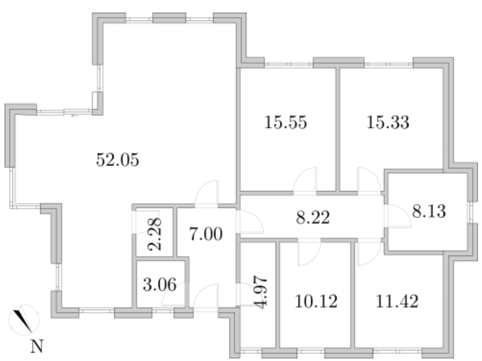
  - The "Physical Power" of the Building: How the house is built, especially its insulation.
    Poor design has consequences!

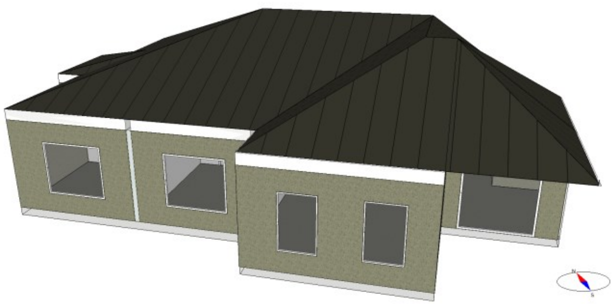
  - The "Digital Brain" of the Building: Smart systems and data analysis that make the building intelligent

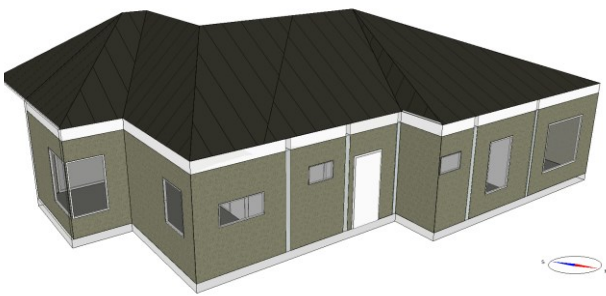
CASE STUDY
Eko Naselje Hrašće

Detailed dynamic simulation model

- Detailed simulation model of the case study house in the professional building simulation software **IDA-ICE**[1]
- Model based on **real construction data** scraped from the project website
- **Location-specific TMY meteorological data** including hourly air temperature, humidity, wind speed, and solar radiation.







[1]Integrated Design and Analysis of Integrated Climate and Energy)

Simulation scenarios

Focus on insulation thickness in key building components:

1. Mineral wool **insulation** thickness in the **roof**
2. Rock wool insulation thickness on the **outer surface of the exterior wall**
3. Mineral wool insulation thickness on the **internal surface of the exterior wall**

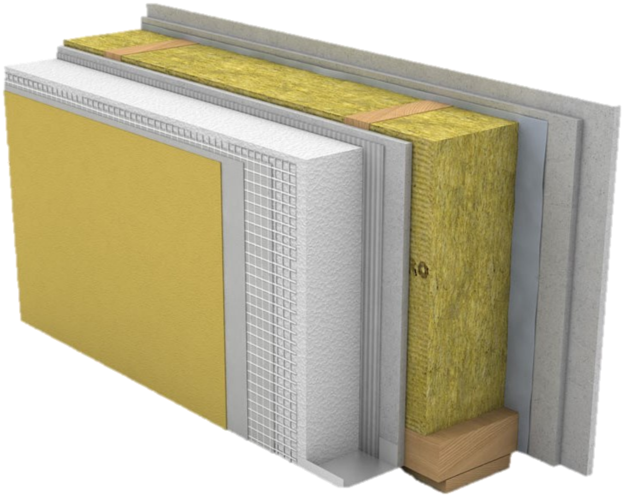
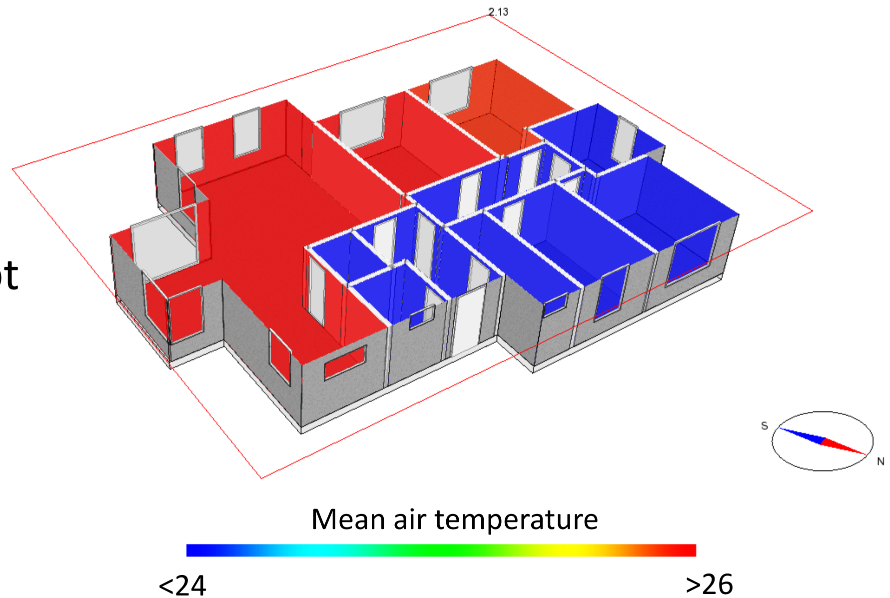


IMAGE SOURCE: https://www.domprojekt.eu/low-energy-prefabricated-houses-p14-37?lang=en

- **Six insulation thicknesses for each area**, ranging from 0.05 m to 0.30 m, based on commercially available materials
- Total of **216 simulation scenarios** combining different insulation thicknesses

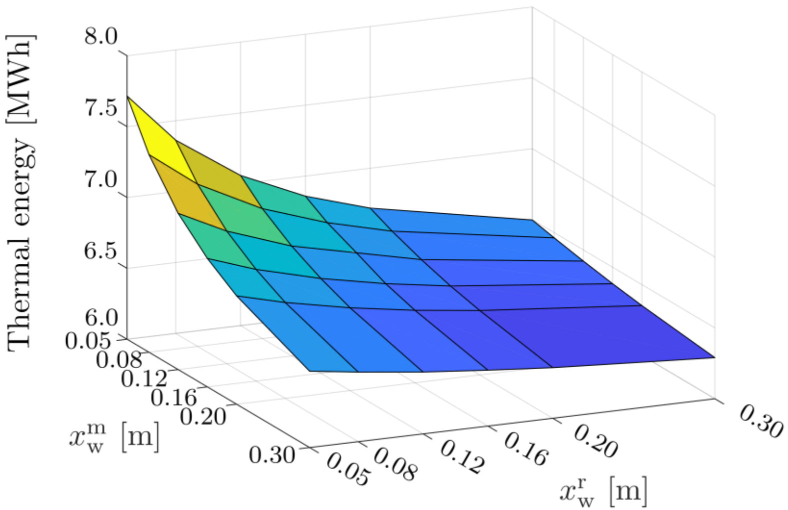
Simulation setup

- Assumed **ideal heating and cooling** systems with sufficient capacity to meet demand
- Comfort temperature setpoints aligned with **ISO 7730** standard:
  - 20°C minimum
  - 26°C maximum
- Heating and cooling available in all rooms except the attic (not intended for living)

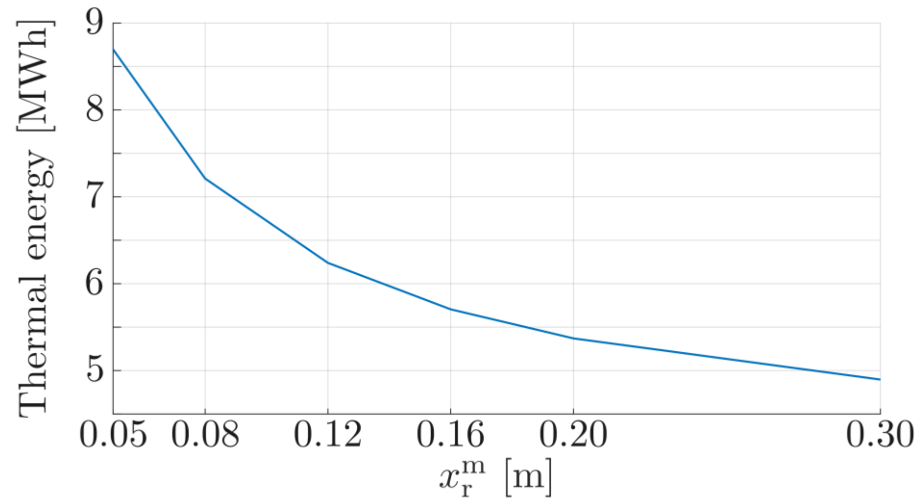


Simulation results: More insulation = less energy?

- More insulation = less heating!



Fixed roof insulation $x_{\mathrm{r}}^{\mathrm{m}} = 0.30$ m



Fixed wall mineral wool insulation $x_{\mathrm{w}}^{\mathrm{m}} = 0.16$ m,
Fixed wall rock wool insulation $x_{\mathrm{w}}^{\mathrm{r}} = 0.16$ m

- Potential savings: Appropriate thermal insulation can produce energy savings ranging from 12.92% to 18.48%

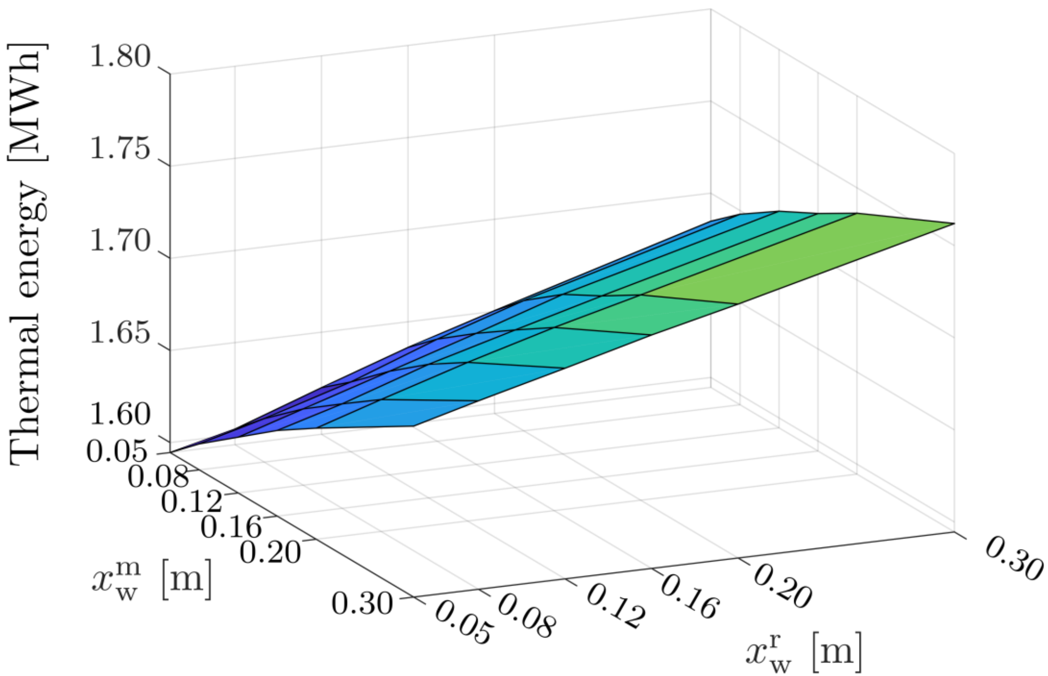
A Small "Catch" for Cooling Energy

- more insulation ≠ less energy

- **Why?** A highly insulated building, it's harder for heat to "escape".

- When the outside temperature is high, the insulation can trap the heat inside, making it more difficult to keep the building cool during the day.

- Careful attention must be paid to balance insulation with other factors, such as **passive cooling**, to maintain a comfortable indoor temperature



Talking Money: The Payback Period!

- The optimal configuration balances energy savings with installation costs.

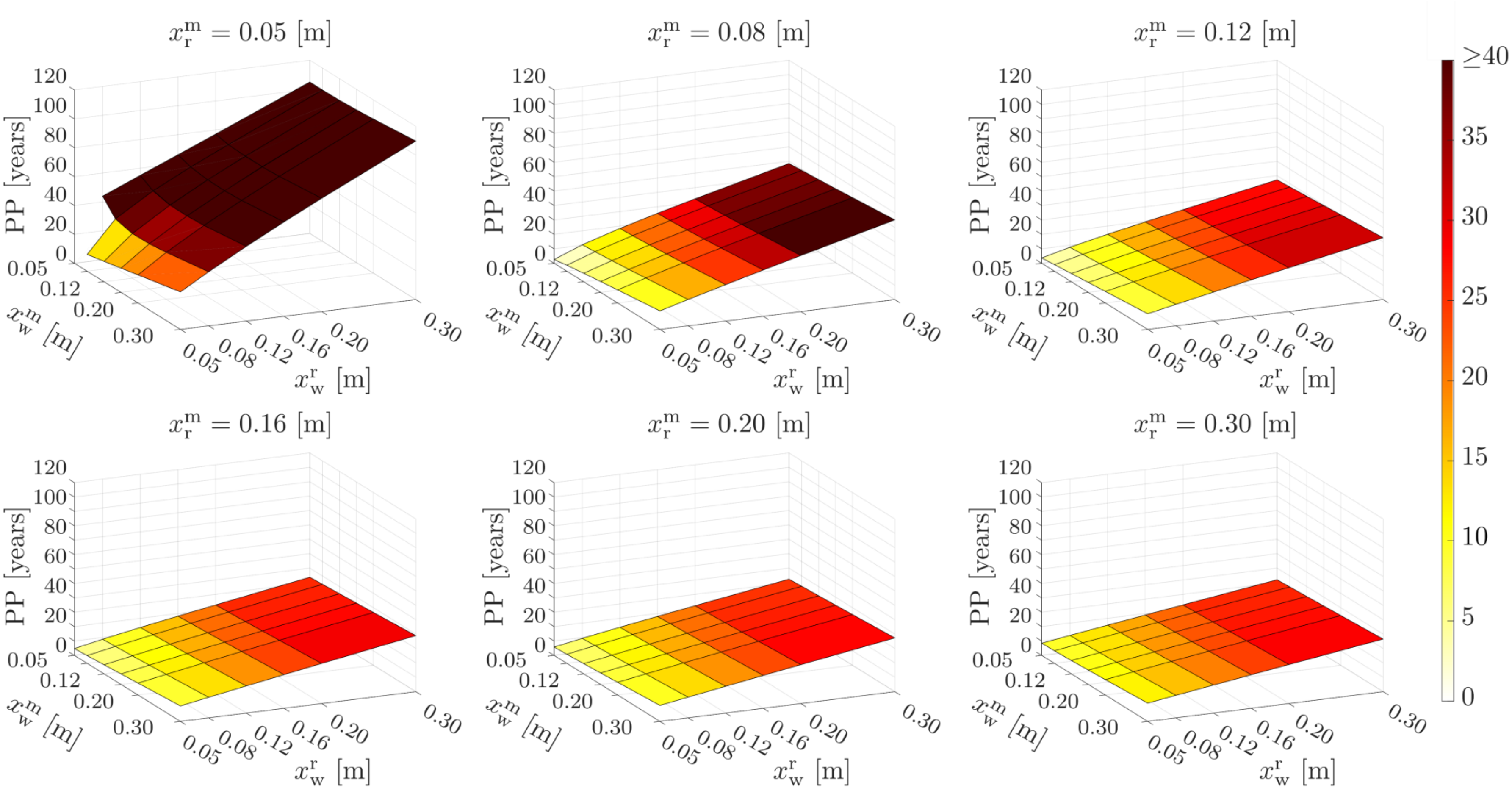
- **Payback Period** (PP): number of years required for the cumulative energy cost savings to equal the additional initial investment

$$PP = \frac{C_{\mathrm{inv},i} - C_{\mathrm{inv},0}}{C_{\mathrm{ae},0} - C_{\mathrm{ae},i}}$$

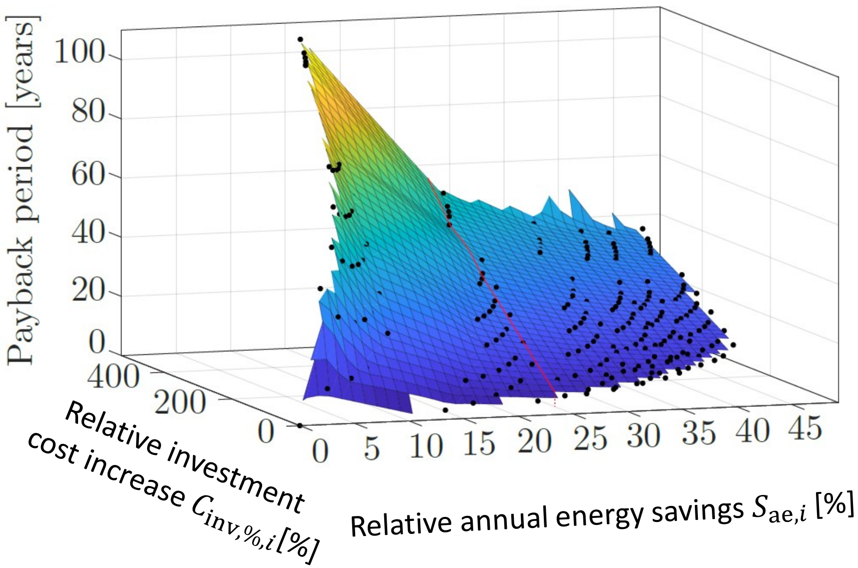
C_{inv} - investment cost of insulation materials [EUR]
C_{ae} - annual energy cost [EUR]

- **Assumptions:**
  - Baseline (scenario 0): minimal insulation (0.05 m for all areas)
  - installation cost are equal for all insulation thicknesses
  - energy consumption translated into cost using a **heat pump system** and COP 3.8
  - energy price considered equal to averaged energy price for households in Croatia
  - insulation material prices taken from the retail stores in Croatia

The Numbers Game: Payback Period in Our Case!



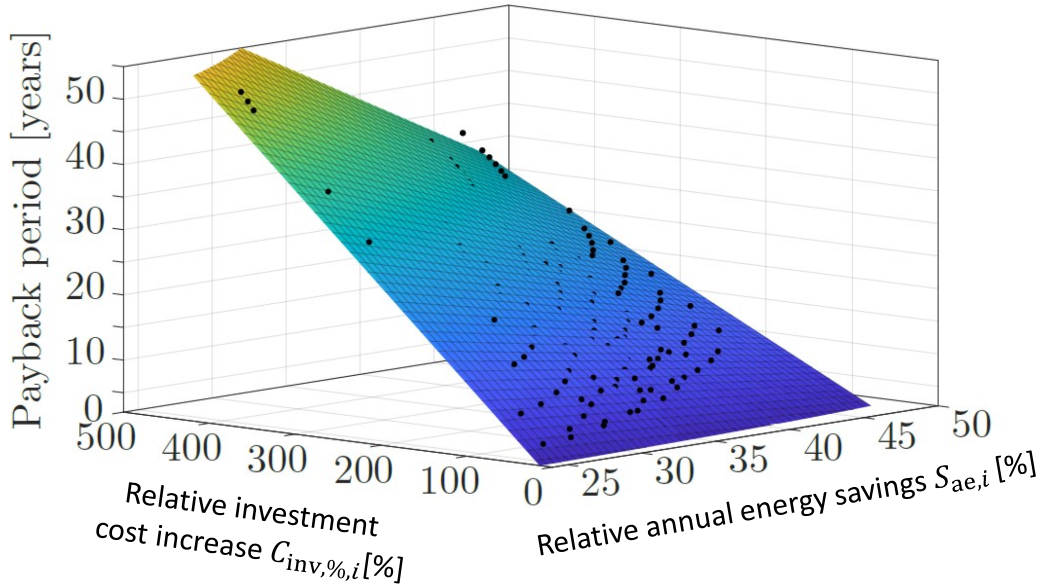
The Numbers Game: Payback Period in Our Case!



If I invest more in insulation, how long will it take to get my money back – and is it wort it?

- even with energy savings of >40%, the PP exceeds 20 years with suboptimal insulation choice
- for energy savings >25%, the relationship between PP, relative investment increase, and annual energy savings is almost linear

The Numbers Game: Payback Period in Our Case!



$$PP_i = p_0 + p_1 \cdot S_{\text{ae},i} + p_2 C_{\text{inv},,i} + p_3 \cdot S_{\text{ae},i} \cdot C_{\text{inv},\%,i}$$

- Simplifies decision-making by replacing complex simulations
- Fast and accurate way for decision makers to identify smart, cost-effective insulation choices

Conclusions & Future Perspectives

- Advanced simulation tools enable precise energy predictions pre-construction
- Optimal insulation depends on:
  - Heating/cooling systems
  - Local climate
  - Insulation & energy costs
- **This results are tailored specifically for our case study**

» Combining multiple scenarios, diverse buildings, and AI can unlock scalable, adaptable solutions

» Benefits homeowners, architects, engineers, contractors, and policymakers

» Especially vital for renovation of energy-inefficient existing building stock

Thank you!

Questions?

Built on the premises of control theory and applications, LARES contributes to improving exploitation and competitiveness of green energy systems and infrastructure.

Find more about our work and ongoing research at https://www.lares.fer.hr