Whole building simulation and Optimization of PCM Integration in buildings

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Introduction

Phase change materials (PCMs) offer valuable benefits in passive energy storage and release within buildings. Their ability to store significant thermal energy within compact volumes makes them ideal for heat storage applications in buildings.

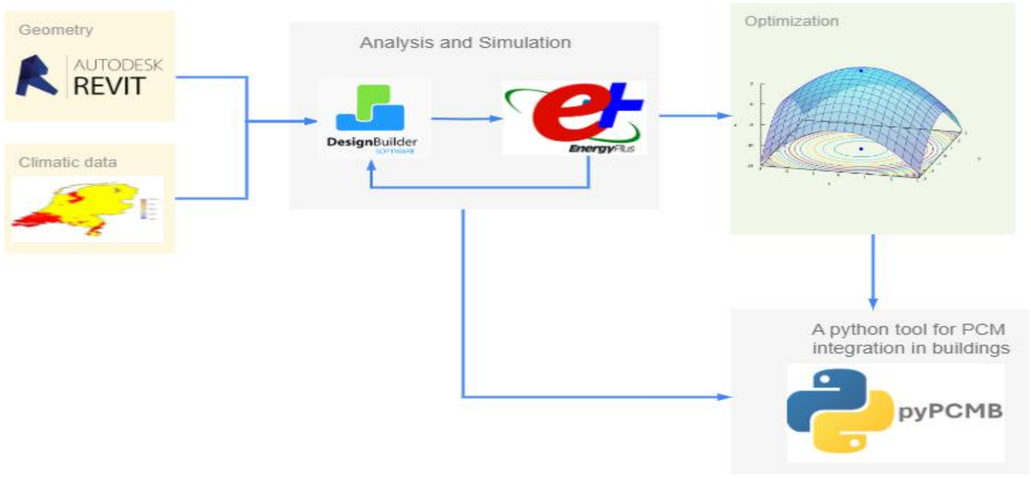
Researchers integrate phase change materials (PCMs) into building components like walls, floors, and roofs to reduce overall energy usage. They explore optimal PCM performance by adjusting factors like thickness and placement, using optimization tools. Despite progress, further research is needed. Our study aims to comprehensively investigate through multi-factor simulation, combining variables like material, quantity, configuration, and location for optimum performance. We'll assess the effectiveness of optimization tools for PCM integration in buildings. effectiveness and aim to develop a user-friendly tool for homeowners to decide on PCM placement and quantity for building efficiency.

Issues with PCM integration in buildings

Incorporating phase change materials into building envelopes poses a substantial challenge due to various factors such as:

- Thermophysical properties of PCM
- Building design
- Encapsulation technique
- Integration method
- Climatic condition

Our Approach



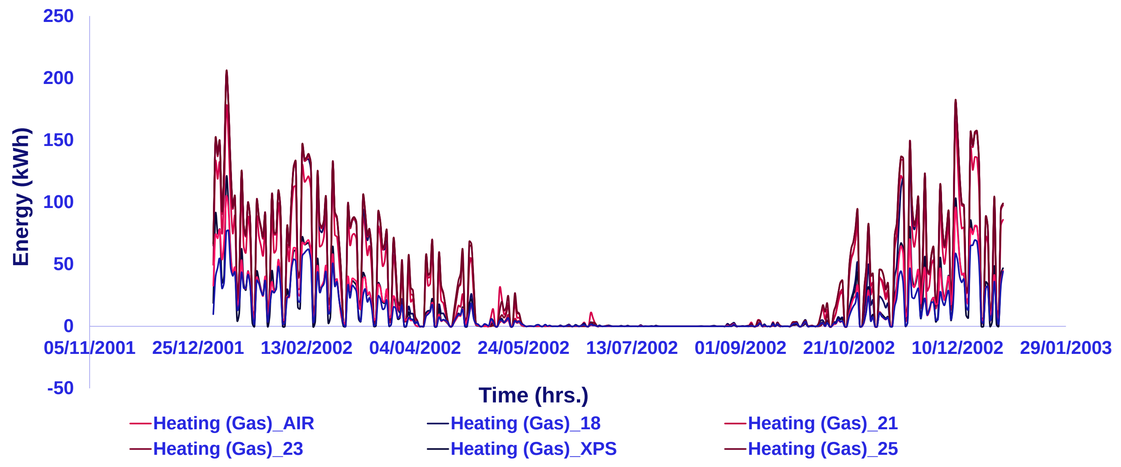
Autodesk Revit was used to design a typical Dutch terrace building, with parameters from [1]. EnergyPlus weather data for Amsterdam, Netherlands, informed our simulations. We explored eight scenarios: six with PCM integrated into walls, and two with air and XPS insulation. EnergyPlus simulations offer robust modeling of phase change materials (PCMs) in building components. Validated by [2], EnergyPlus employs a conduction finite difference algorithm, allowing users to choose between Crank-Nicholson or fully implicit schemes. This accurately captures PCM thermal performance. The equation for the fully implicit scheme within a homogeneous material is as follows

$$\frac{\rho C_p \Delta x (T_i^{j+1} - T_i^{j})}{\Delta t} = \frac{k_w (T_{i+1}^{j+1} - T_i^{j+1})}{\Delta x} + \frac{k_e (T_{i-1}^{j+1} - T_i^{j+1})}{\Delta x} \quad (1)$$

i = node being modeled, i+1 = adjacent node to interior of wall, i-1 = adjacent node to exterior of wall;
j + 1= new time step, j = previous time step; kw and ke are the thermal conductivity for the interface between i node and i+1 node, and between i node and i-1 node. All other parameters retail their usual meaning.

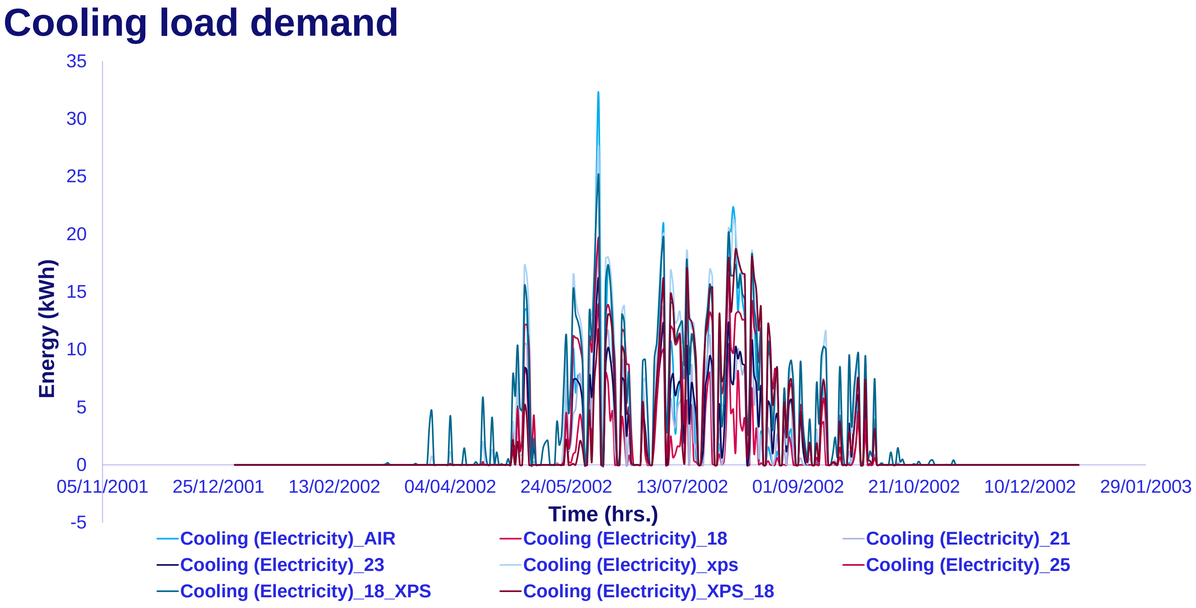
Where we are

Heating load demand



The heating load graph highlights the superior performance of the XPS-insulated wall in reducing heat loss. This aligns with expectations, as winter ambient temperatures typically don't reach PCM melting points, minimizing phase changes. Numeric values denote PCM phase change temperatures.

Cooling load demand



The cooling load profile plots show that PCM_18 performed the best, needing the least cooling energy. This is anticipated because its melt fraction will be higher when compared to other PCMs utilized.

Next steps

The next phase of our study will focus on evaluating optimization algorithms for PCM integration in buildings. Subsequently, simulation and optimization results will inform the development of our tool, addressing both initial use case scenarios and future modifications.

Conclusion

- Phase change materials (PCMs) may not transition during winter if outside temperatures don't reach their melting point.
- Multi-objective algorithms optimize PCM use in buildings, necessitating evaluation against building objectives.
- Developing pyPCMB, a user-friendly tool, will estimate PCM quantity and location, providing insights to homeowners and engineers about potential energy savings from home upgrades..

References

1. Middle house RVO.nl [Online]. Available: https://www.rvo.nl/onderwerpen/ duurzaam-ondernemen/gebouwen/wetten-en-regels-gebouwen/nieuwbouw/energieprestatie-epc/referentiewoningen-epc/tussenwoning
2. Tabares-Velasco, P. C., Christensen, C., & Bianchi, M. (2012). Verification and validation of EnergyPlus phase change material model for opaque wall assemblies. Building and Environment, 54, 186–196.