Integrating comfort in ESM - Optimisation of costs, carbon emissions and thermal comfort in a building-level energy system model

David Huckebrink

Jonas Finke

{huckebrink,finke}@ee.rub.de

RUB

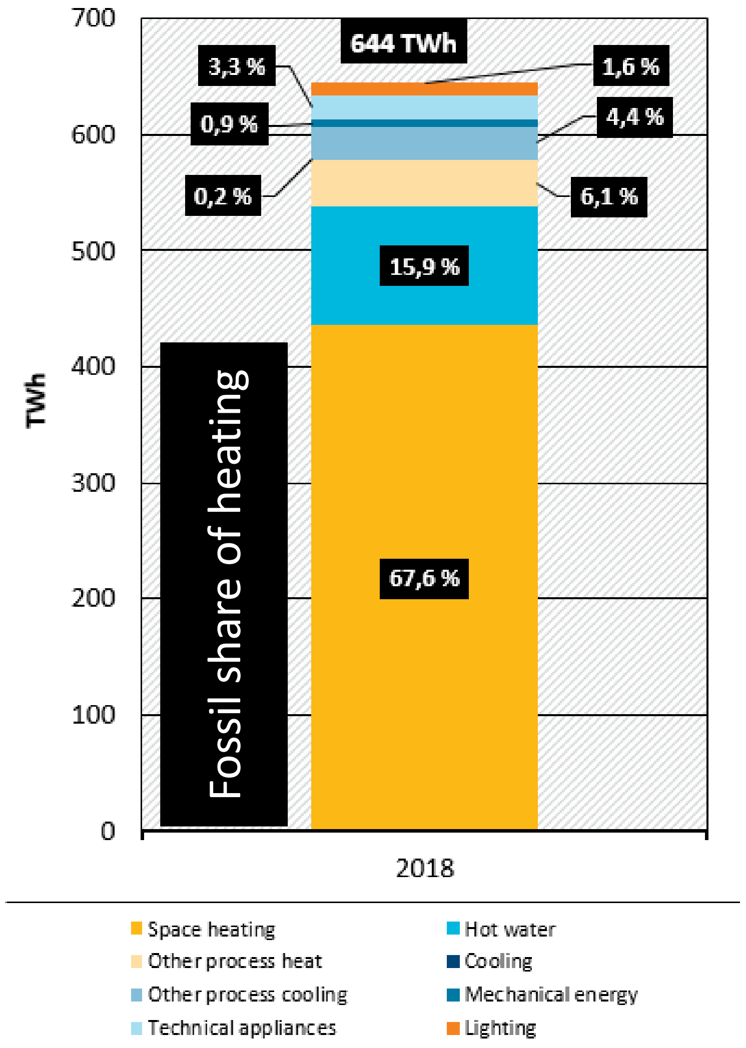
Chair of
Energy Systems &
Energy Economics

Outline

- Motivation
- Methods
- Results
- Discussion
- Conclusion

Motivation

- Neither heating nor behaviour is well addressed in ESM
- Households account for ~28,9% of final energy consumption[1]
- Heating accounts for > 80% of energy use in households[2] and is largely fossil fuelled (>75%)[2]



How can humans contribute/ participate?

1) https://ag-energiebilanzen.de/daten-und-fakten/auswertungstabellen/
2) https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#endenergieverbrauch-der-privaten-haushalte

Motivation

Energy ministers reach deal on EU-wide 15% gas reduction plan COMMENTS

By Jorge Liboreiro & Alice Tidey • Updated: 26/07/2022

euronews.

German cities impose cold showers and turn off lights amid Russian gas crisis

The Guardian

Germany's largest landlord to reduce heating for tenants to save energy

REUTERS

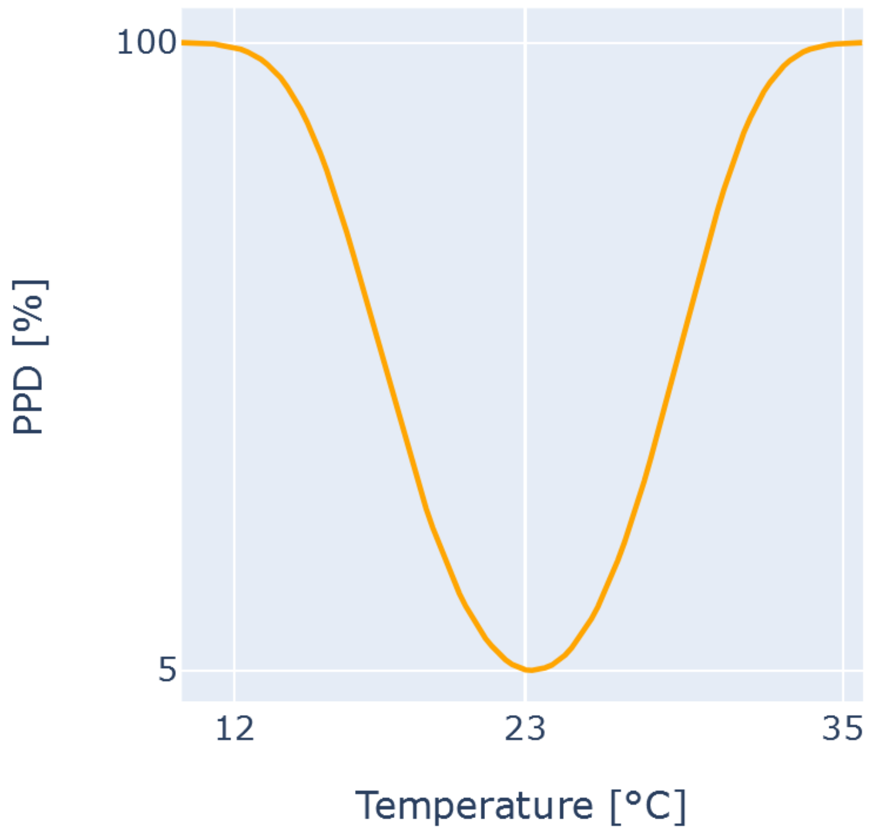
Might be uncomfortable, but
how to assess that?
And is that really efficient?

Methods

Thermal Comfort – Predicted percentage dissatisfied (PPD)

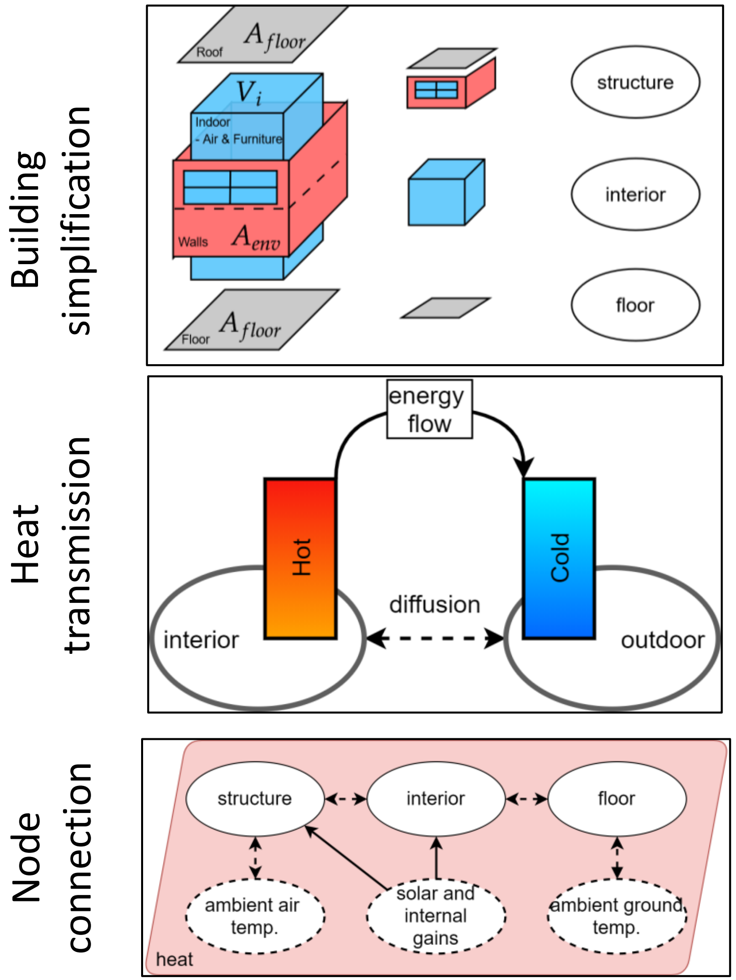
- Used in international standards for building design[1]
- Calculation requires temperature, ~~humidity, air speed, activity &~~ clothing level
- Predicts percentage of thermally dissatisfied people of large group

→ How to integrate that into ESM?



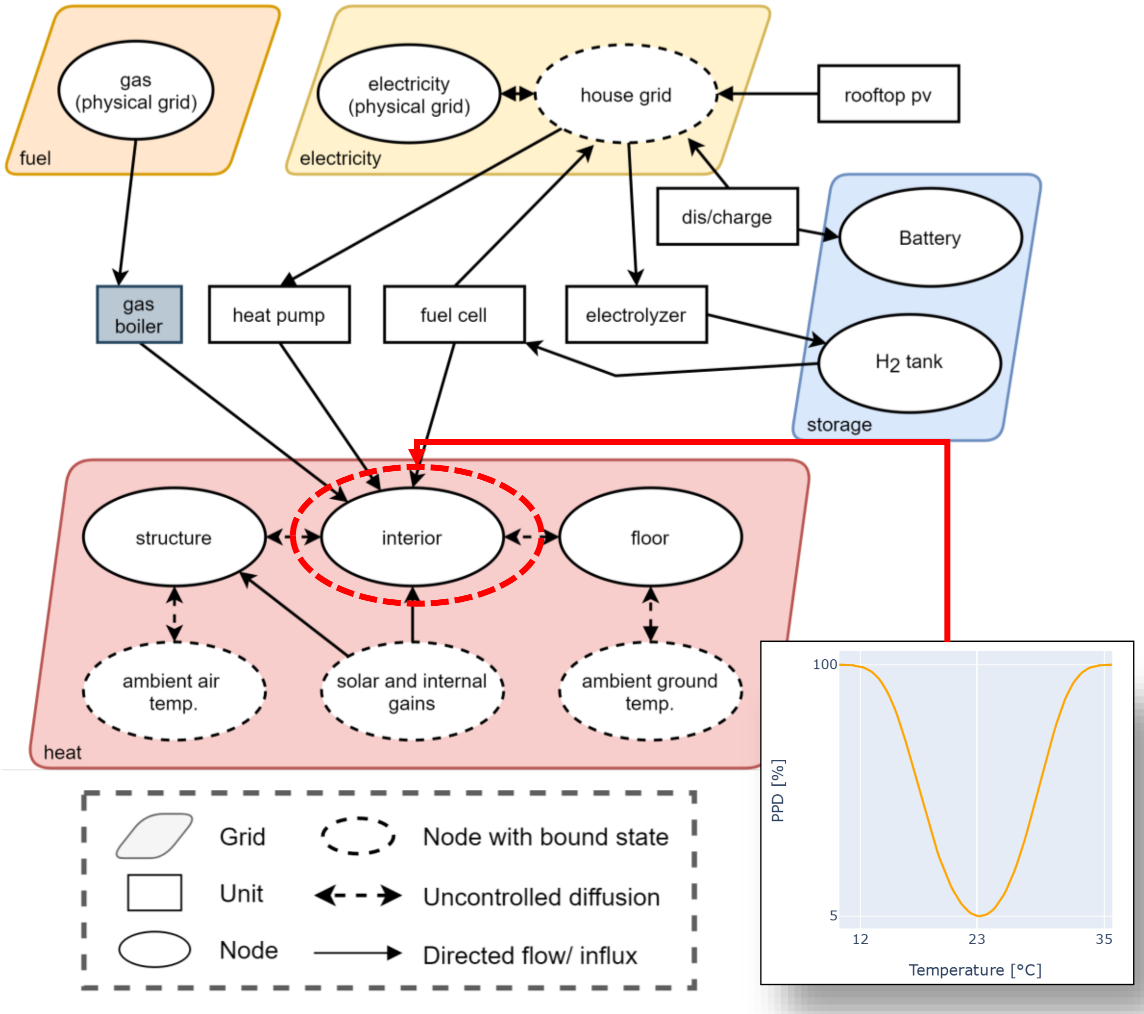
1) ISO_7730

Building model – implemented in Backbone



Structure of thermal model

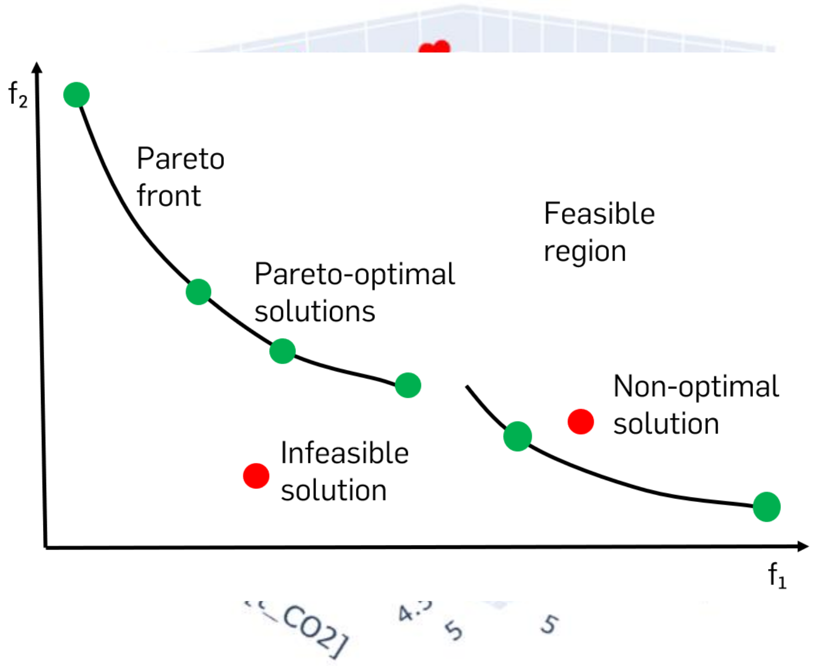
Interlinking with technologies



Final model

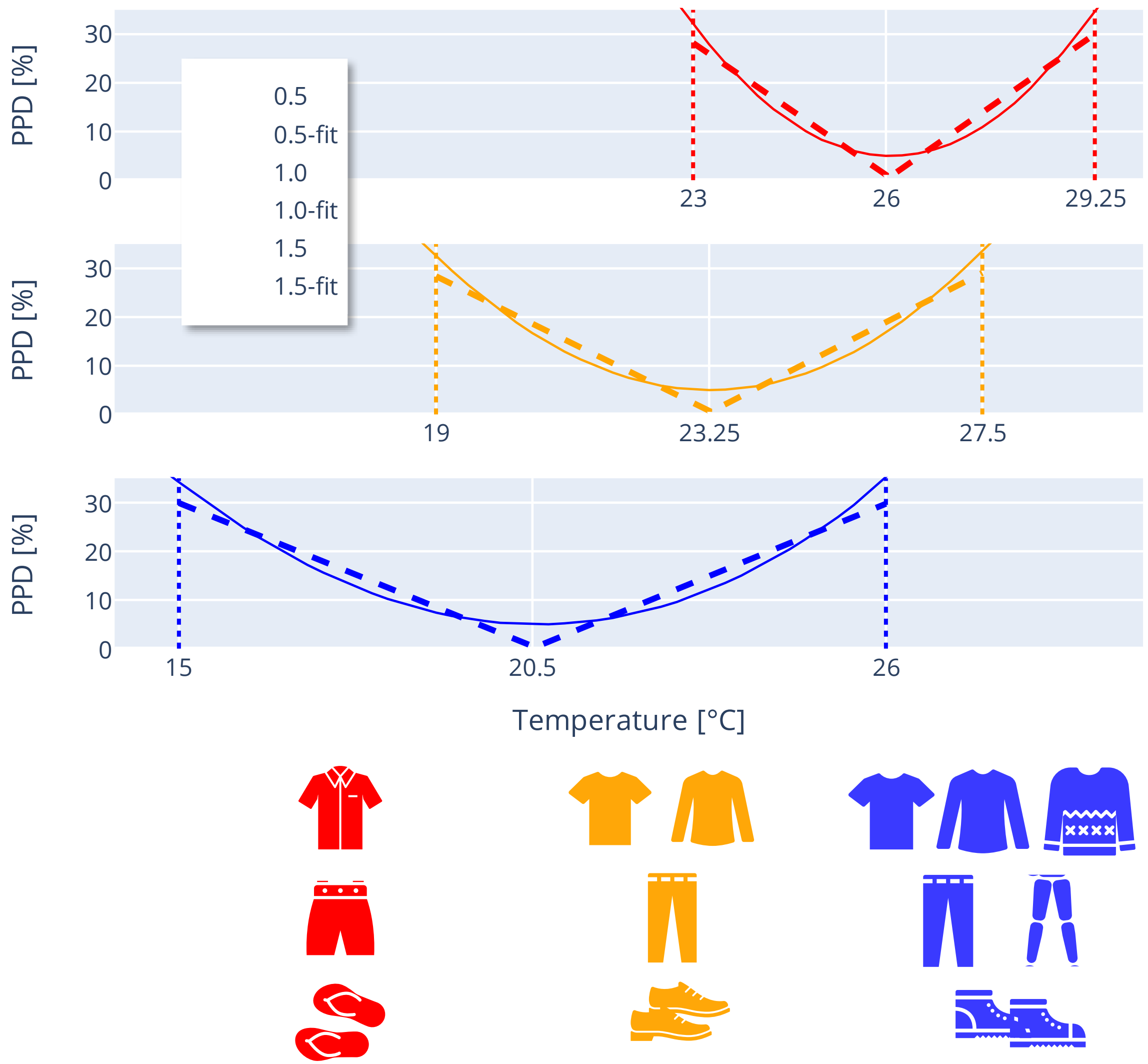
Multi-Objective Optimisation – AUGMECON

- Simultaneous optimisation of multiple objective functions
- Reformulate all but one objective to constraints & introduce slack variables
- Can be used for arbitrary number of objectives (i.e. 3)

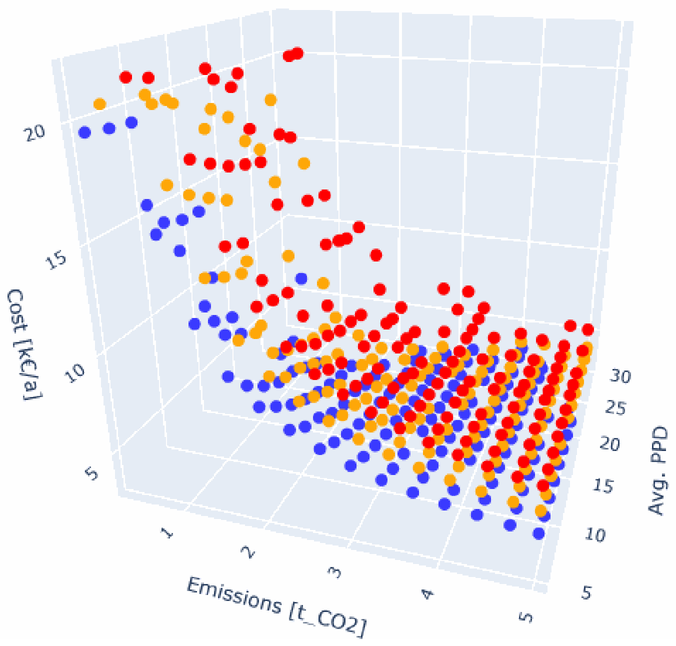


$$\min_{x \in V} \quad \{f_1(x), f_2(x), \ldots, f_k(x)\} \quad \longrightarrow \quad \min_{x \in V} \quad \left(f_j(x) + c \sum_{i \in K} s_i \right) \quad \text{s.t.} \quad f_i(x) + s_i = \varepsilon_i \; \forall \; i \in K \setminus \{j\}$$

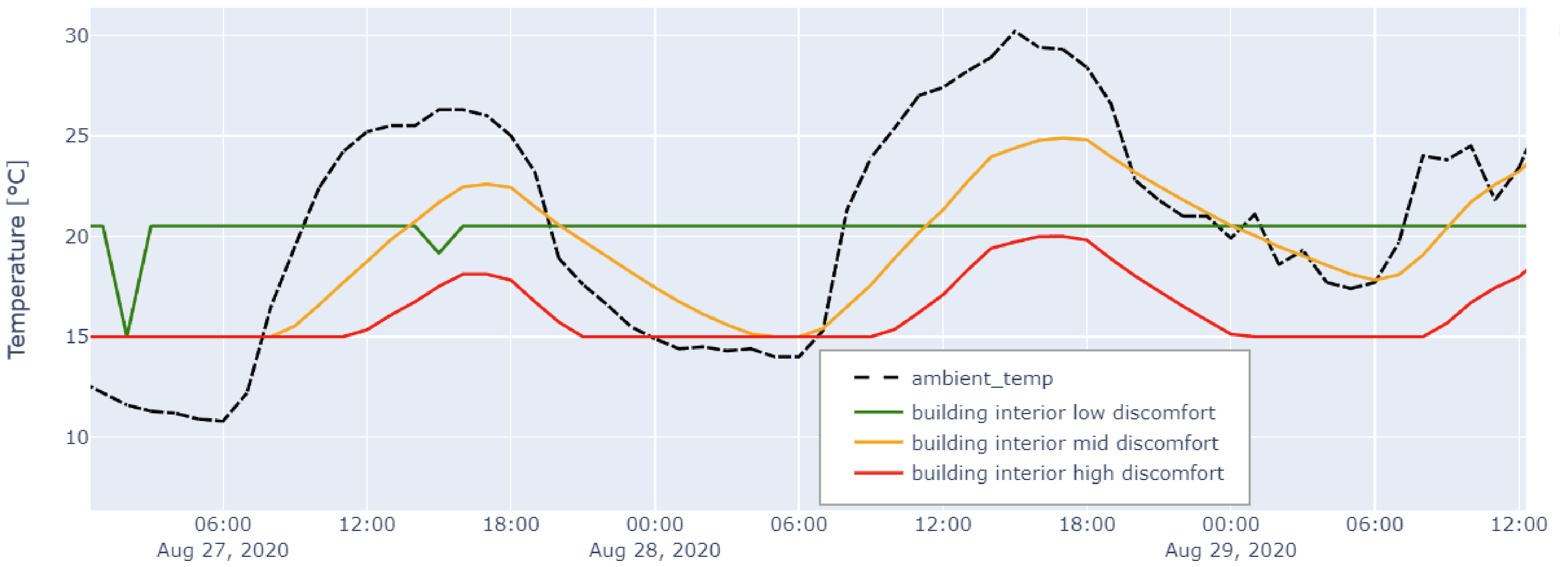
Thermal Comfort – Clothing ensembles



$$\text{Avg. } PPD = \frac{\sum_{t=1}^{8760} k \cdot |T_{set} - T_{interior,t}|}{8760}$$



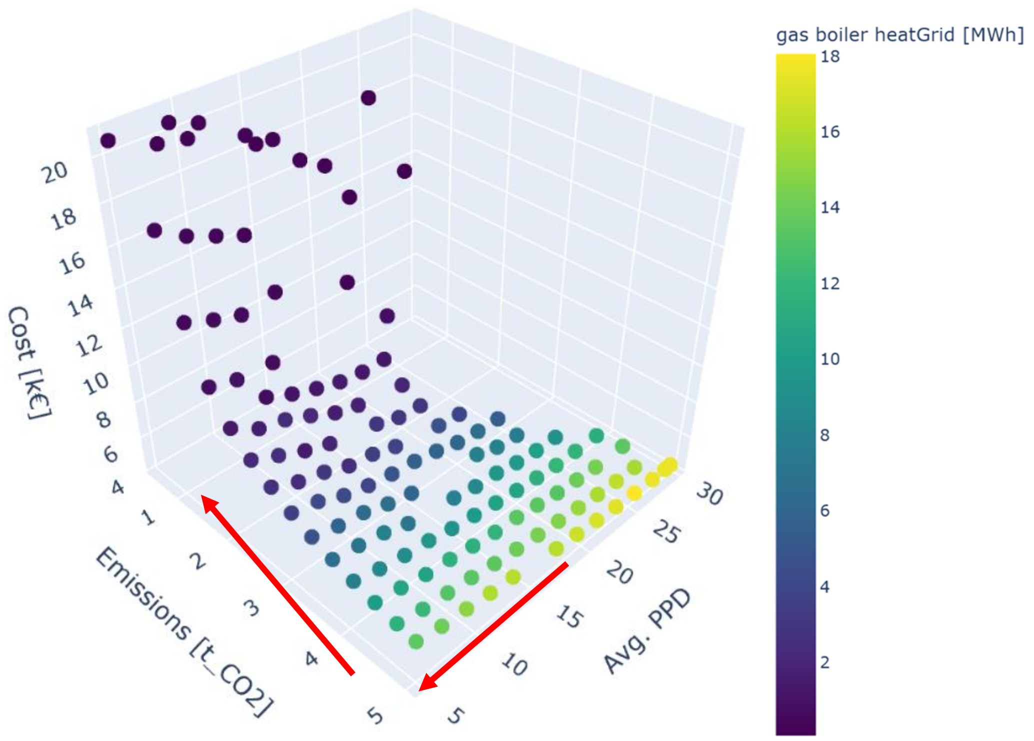
Effects of comfort constraint

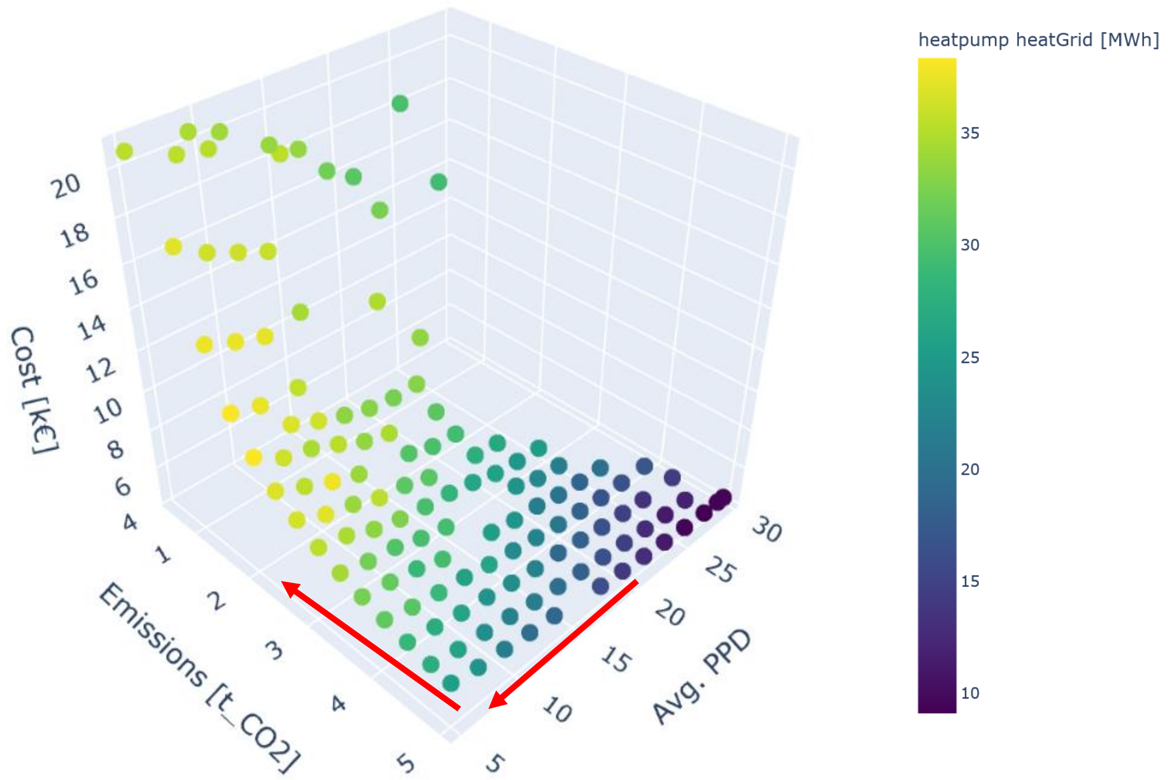


- Low discomfort → Temperature steady at set temperature
- Mid discomfort → Temperature often following ambient temperature
- High discomfort → Temperature at boundaries, sometimes following outdoor temperature

Results

Results – Heat provision

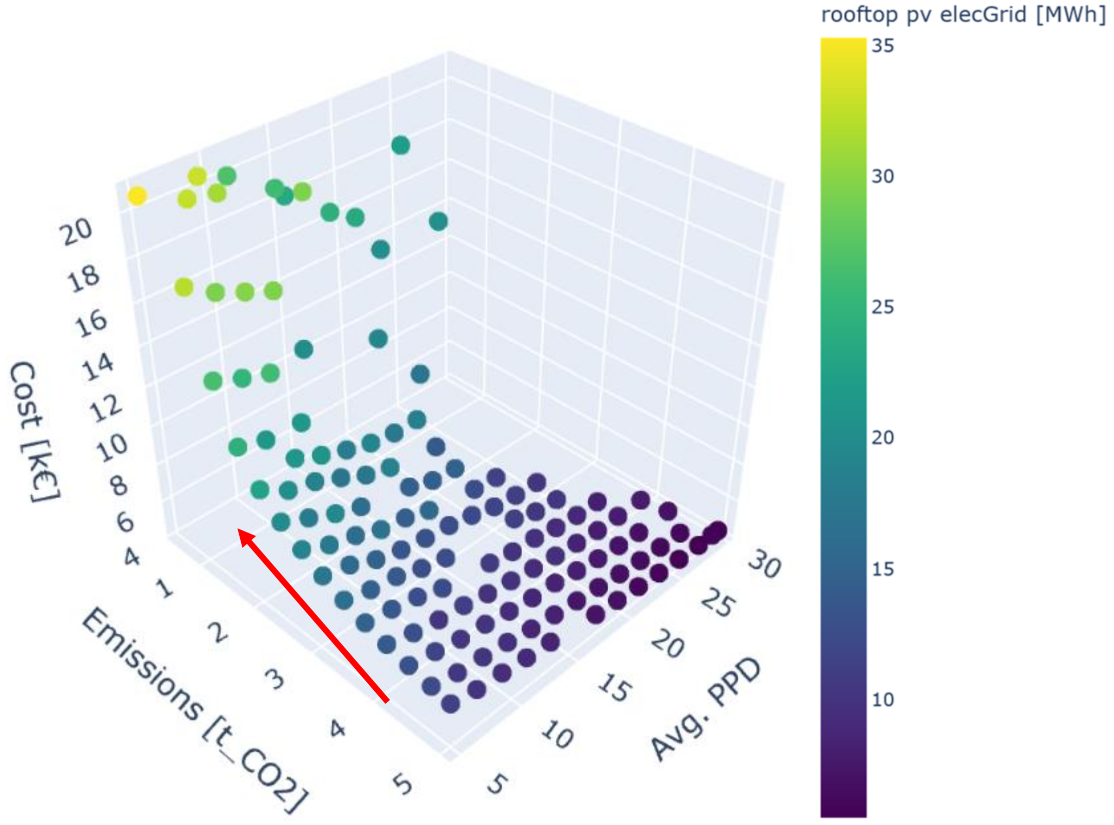


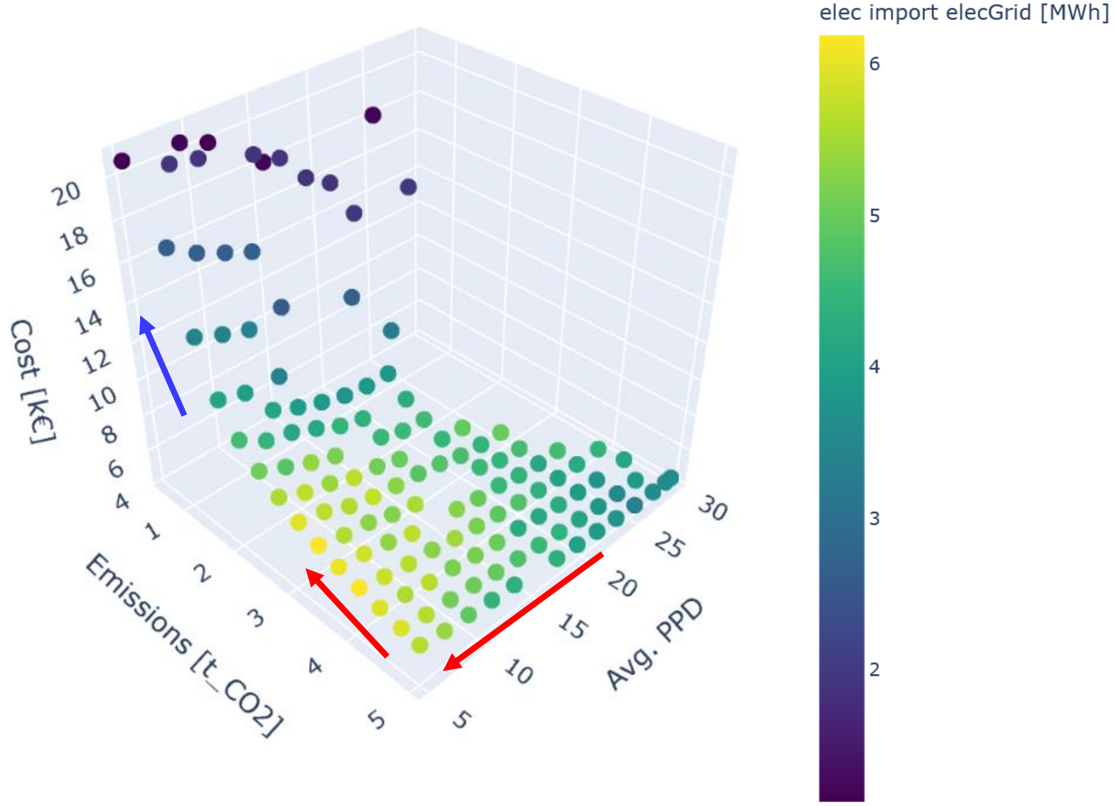


- Lower emissions → lower gas boiler usage
- Lower discomfort → lower gas boiler usage

- Lower emissions → higher heat pump usage
- Lower discomfort → higher heat pump usage

Results – Electricity provision





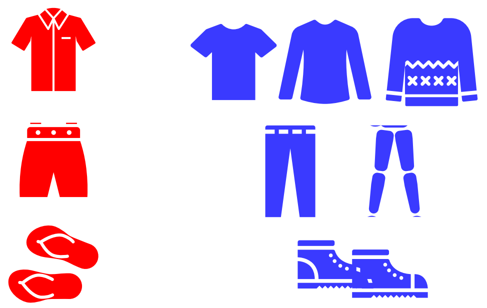
- Lower emissions → more pv generation
- Lower discomfort → slightly more pv at low emissions

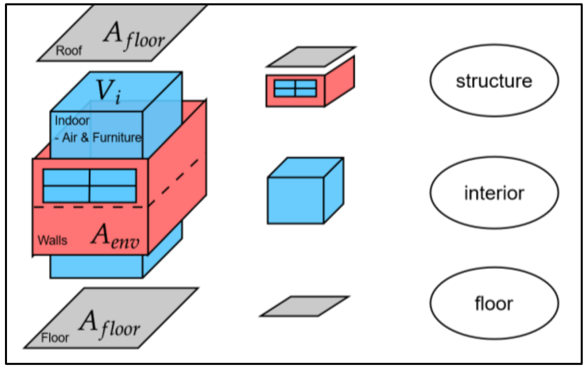
- Lower emissions → more procured electricity (at first)
  - low emissions → less procured electricity
- Lower discomfort → more procured electricity
  - Increased heat pump utilisation

Limitations & Conclusions

Limitations

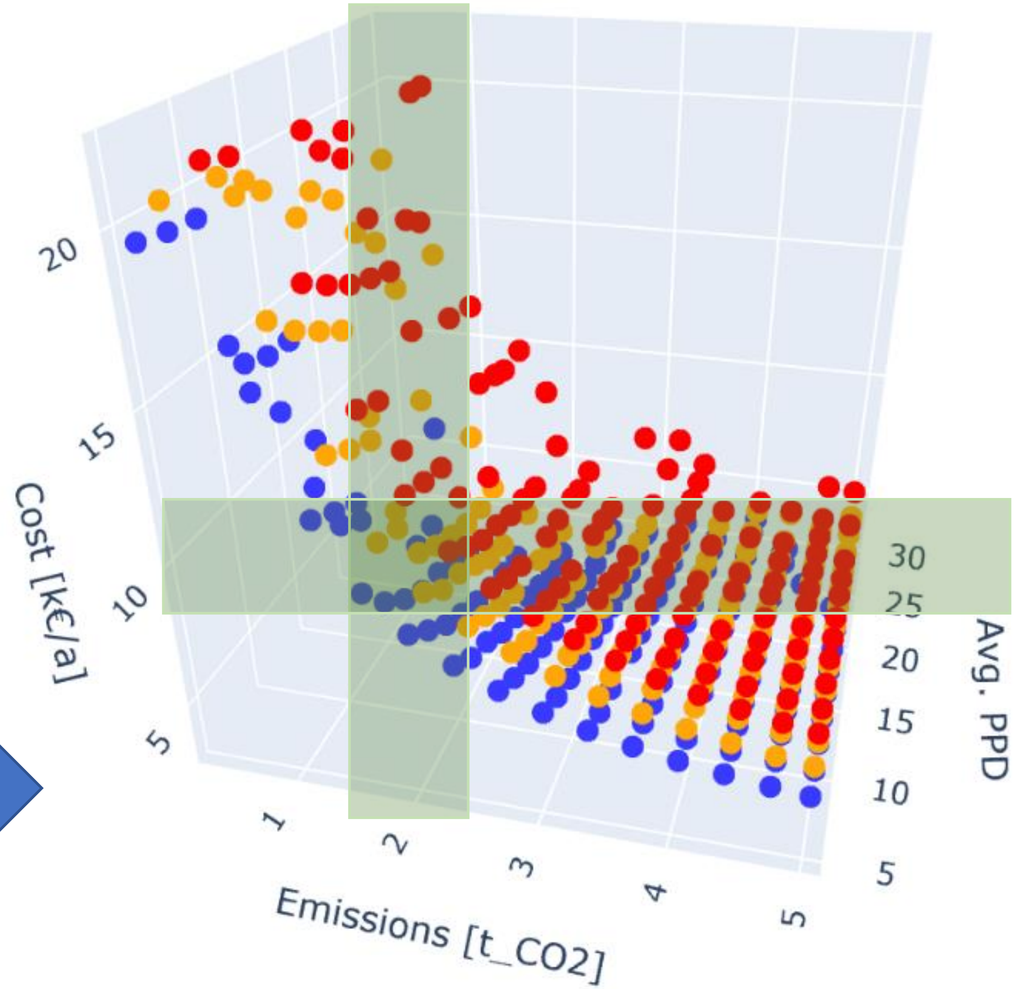
- Static clothing levels
  - One has to wear a sweater in the summer (or shorts in the winter)
- Static description of comfort
  - i.e. we don’t account for discomfort induced by heating fast
- Very coarse building model
  - 1 interior node, no unconditioned zones
  - No thermal buffer storage





Conclusion

- The consideration of thermal discomfort clearly shows a large potential for saving energy
- Inclusion of the three clothing levels illustrated simple method with a significant impact (Cost & Emissions)
- Example: “How to achieve a certain decarbonisation goal with a restricted budget?”



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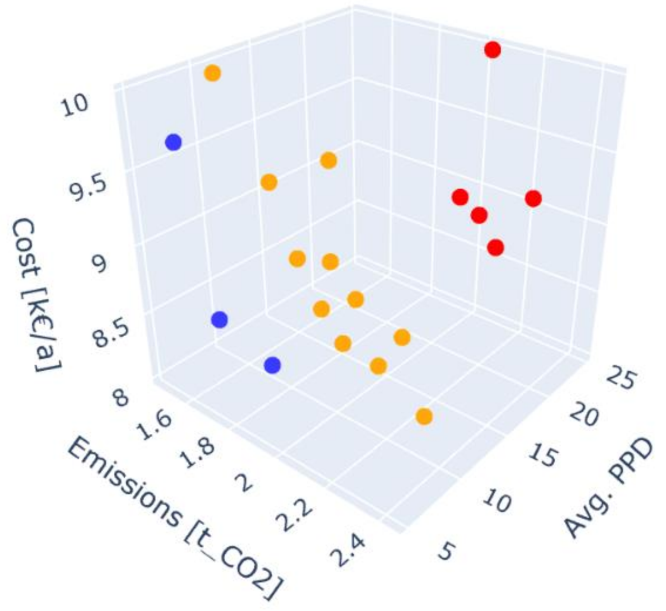

Solution space when aiming for a ~60% CO2 reduction with an annual budget of 8-10 k€.

Outlook

- Thermal (buffer) storages
- Dynamic clothing levels
- Representative building typologies

Thank you for your attention!

huckebrink@ee.rub.de

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