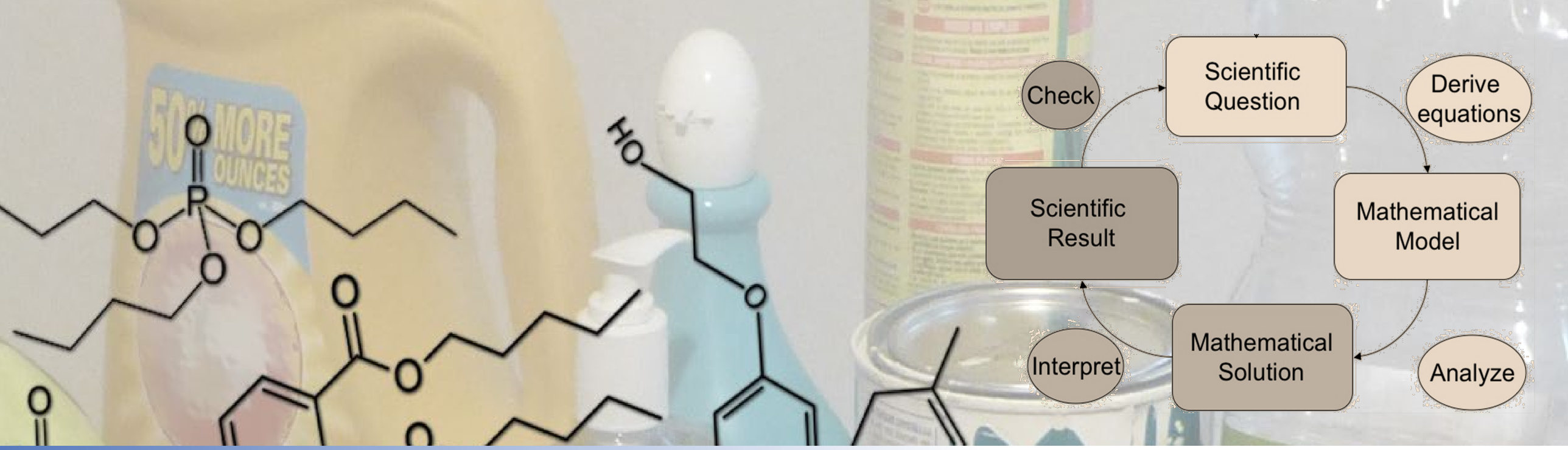


Assessment of Environmental and Human Health Impacts of Plastics in Construction

Prof. Olivier Jolliet, Quantitative Sustainability Assessment, DTU-Sustain
Dr. Alice Micollier

USEtox®

Towards healthy and sustainable food systems

- Where do we need to go?
  Absolute Sustainability - How good is good enough?

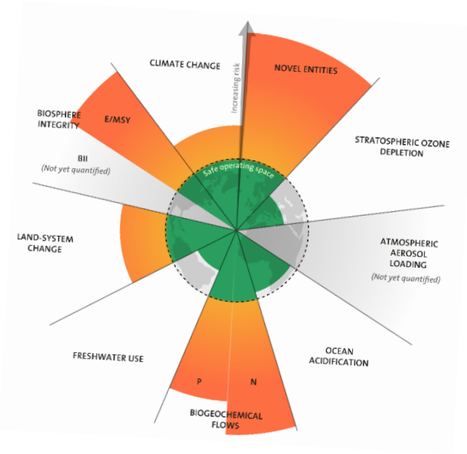
- What do we need to avoid ?
  The challenge of air quality
  → Combined quantification of sustainability and health

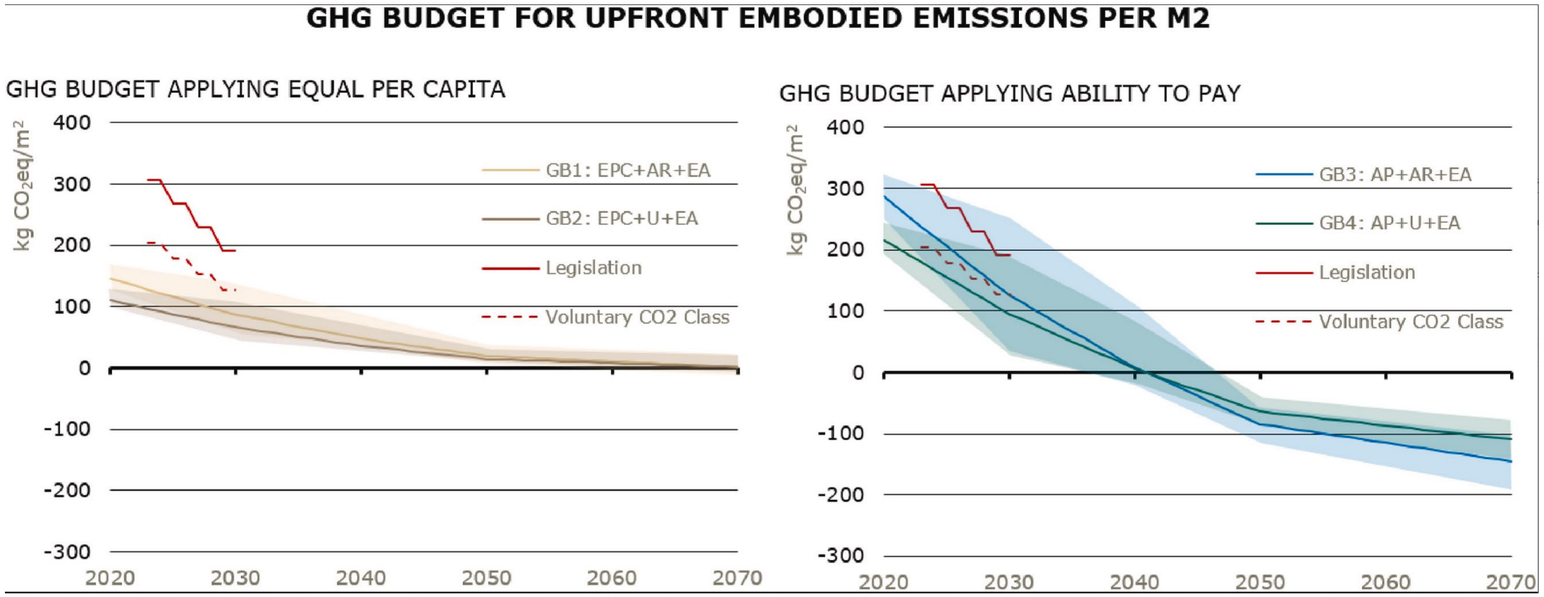
- What are the impacts and benefits of (chemicals in) insulation materials
  Comparison of indoor vs outdoor insulation materials

- Which chemicals of concern to substitute in priority?

What is good enough ? Absolute sustainable buildings

- Design trajectories from present to absolute sustainable building
  - Present DK emission: 8200 kg_{CO2e}/cap/yr
  - Target = 350 kg_{CO2e}/cap/yr
  - → Reduction factor 23





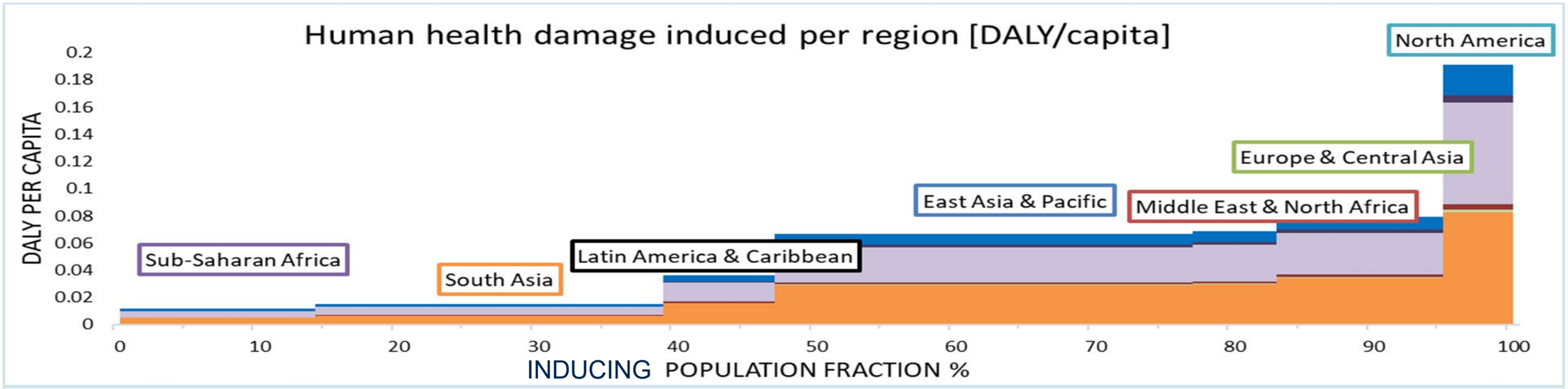
Downscaling of 1.5 C objective Horup et al, 2023, Building and Environment 230 (2023) 109936 –

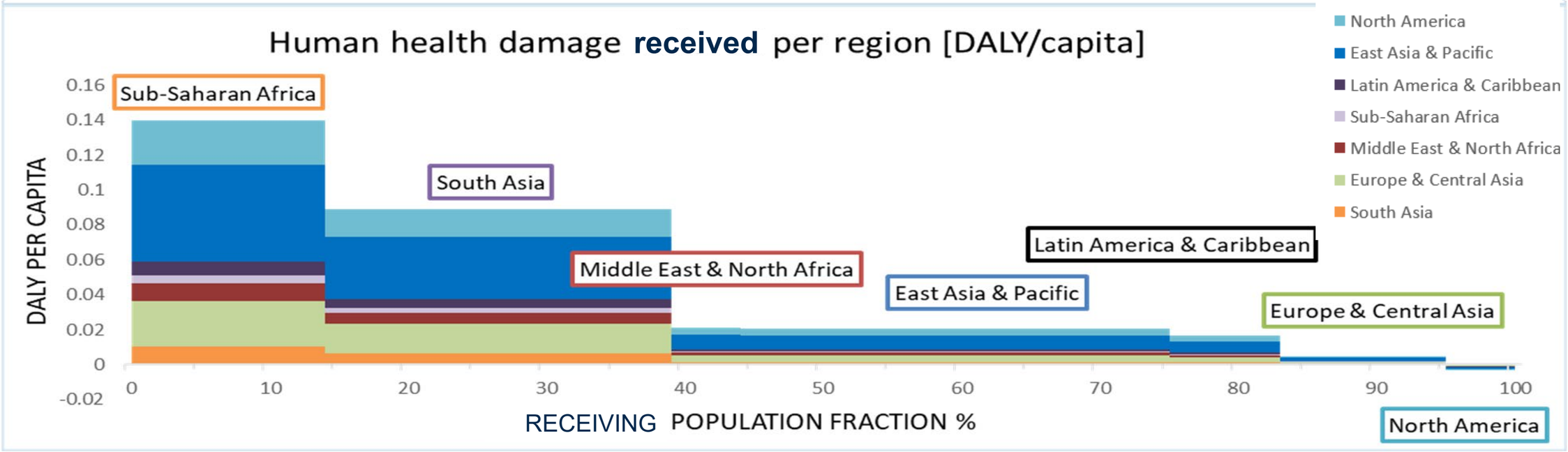
→ Reduction in operation energy and emissions

→ Decarbonization of heat and power production

→ Decarbonization of building material construction, renovation and production

Disparities: Climate change impacts of heat and cold on health

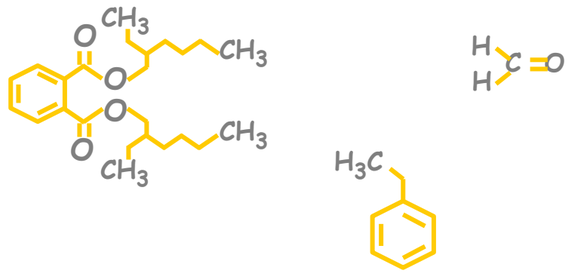




Building sustainability? The challenge of indoor air quality!

Increase of buildings airtightness

Increase use of synthetic materials



Deterioration of indoor air quality???

Inner vs Outer insulation case study

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Building and Environment 230 (2023) 109994

A life cycle approach to indoor air quality in designing sustainable buildings: Human health impacts of three inner and outer insulations

Alice Maury-Micolier [a], Lei Huang [b], Franck Taillandier [c], Guido Sonnemann [d], Olivier Jolliet [b,e,*]

Which material?

Polyurethane foam (PU) XPS, & EPS insulation in a concrete frame structure, 20cm

Outer versus inner insulation

Which chemicals?

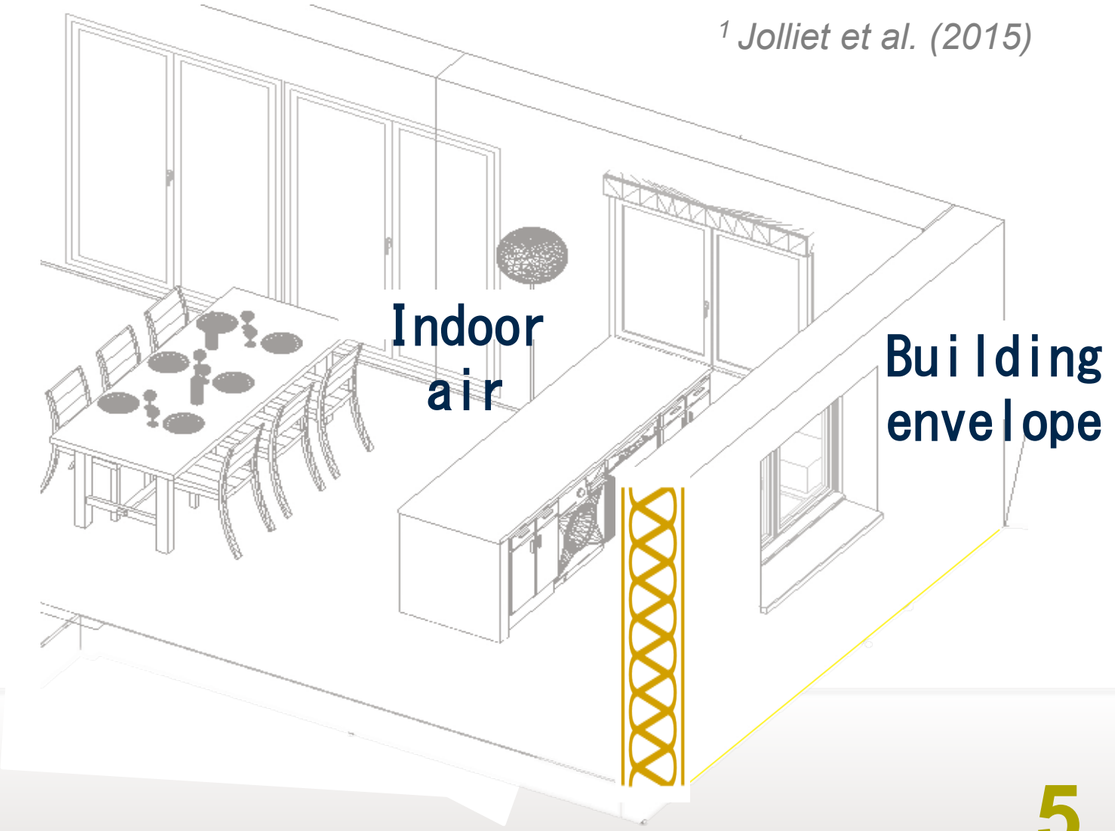
Formaldehyde, 2-Butoxyethanol & DEHP

How long? The next 50 years

Exposure is assessed by the **Product Intake Fraction**[1]

(PiF, $kg_{intake}/kg_{initial}$) – fraction of chemical in the product that is taken in

[1] *Jolliet et al. (2015)*



Coupled model of energy and chemical masses

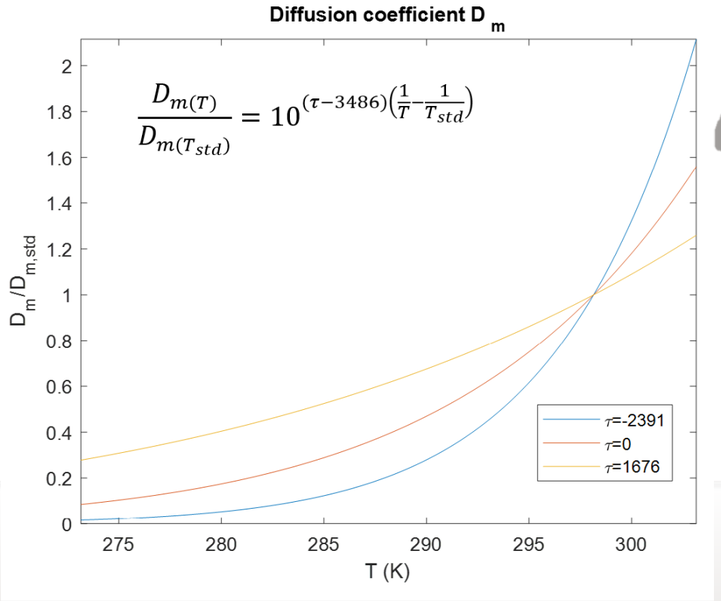
System of 2N coupled ordinary differential equations, with N the number of nodes in the building envelope

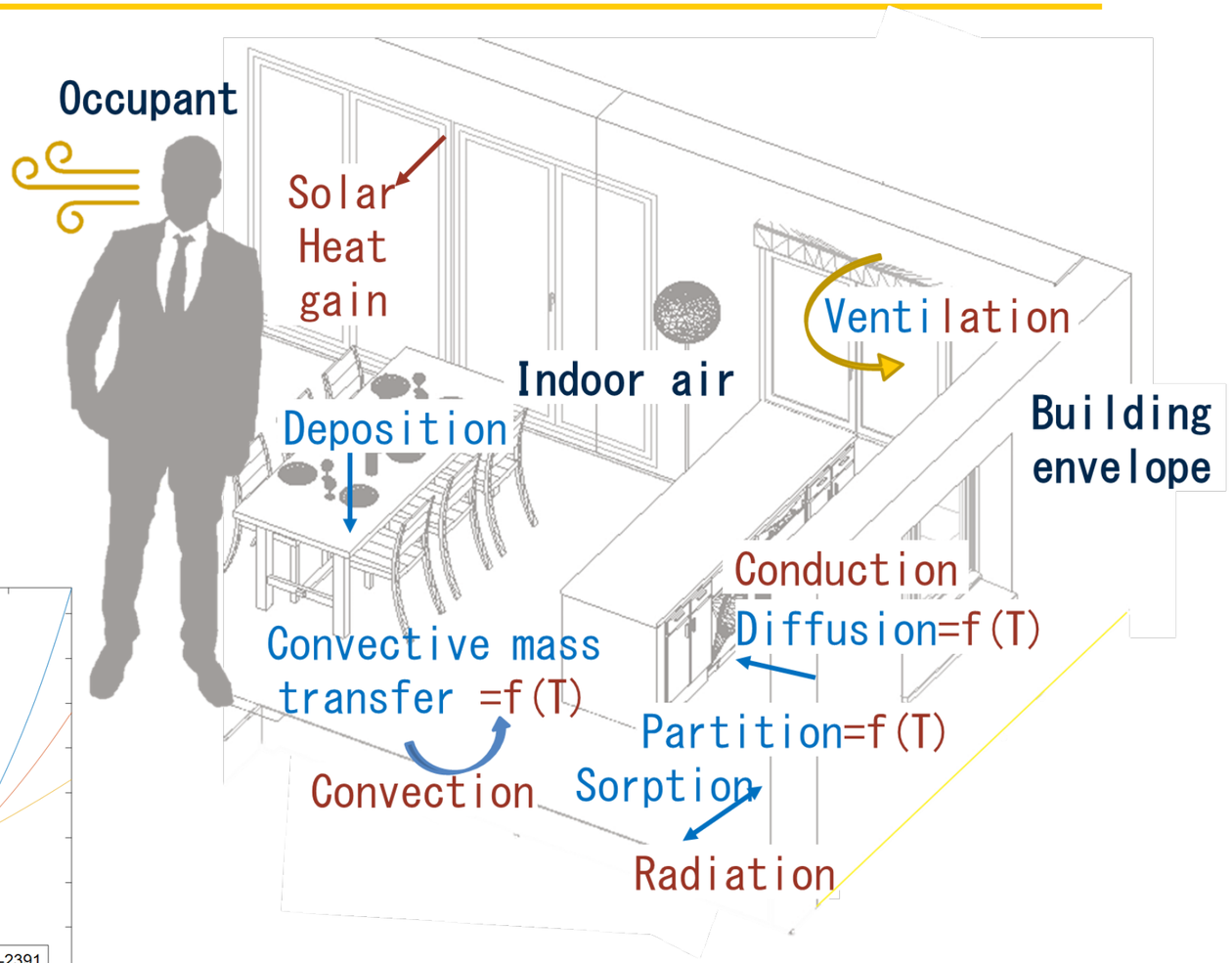
Mass transfer

Heat transfer

$$\begin{bmatrix} \frac{dC_i}{dt} \\ \cdots \\ \frac{dT_i}{dt} \end{bmatrix} = A_s \begin{bmatrix} C_i \\ \cdots \\ T_i \end{bmatrix} + B_s$$

Enables to account for changes in parameters, e.g diffusion with temperature

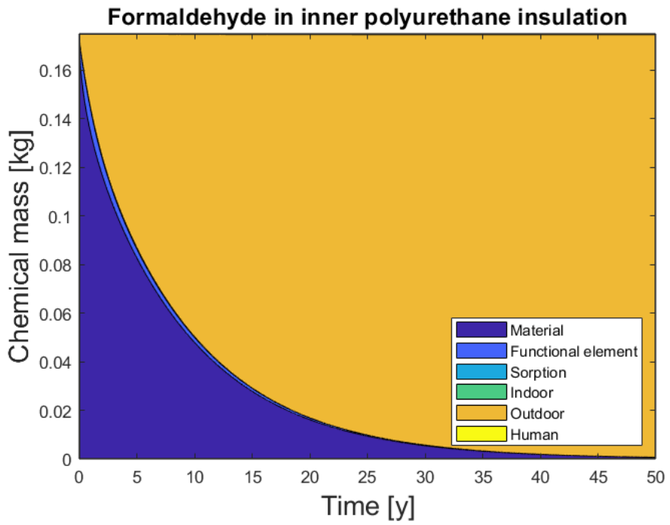


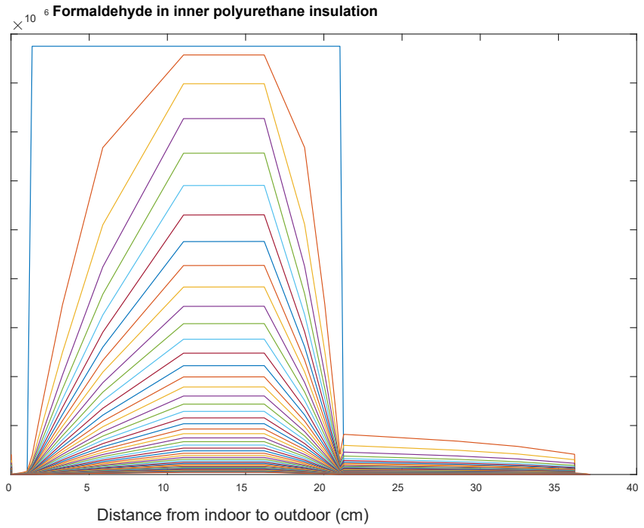


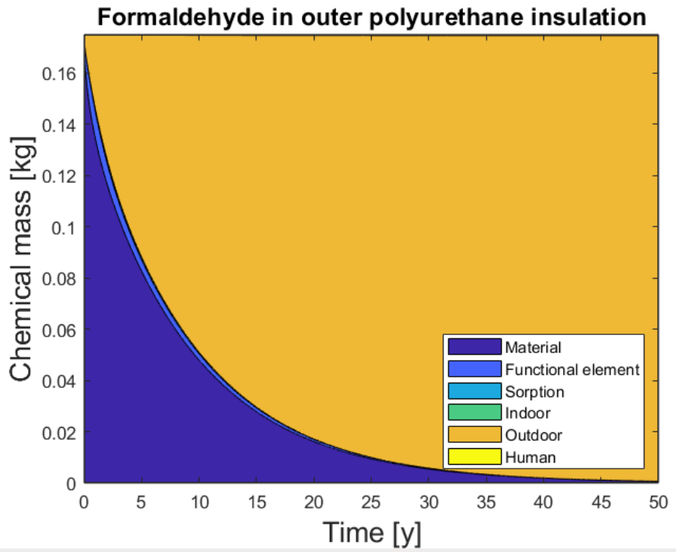
RESULTS: WHAT MATTERS FOR INDOOR EXPOSURE?

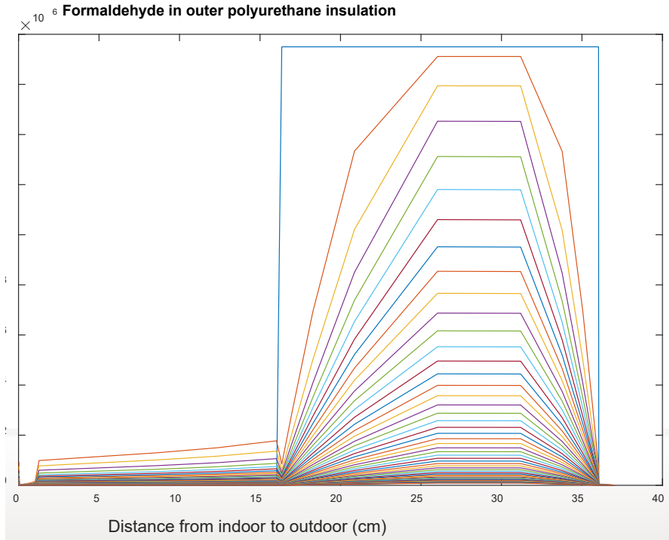
Surprisingly, not the position of the insulation inner/outer for VOCs

Surprisingly, not the position of the insulation inner/outer for VOCs, nor the thickness of the concrete layer



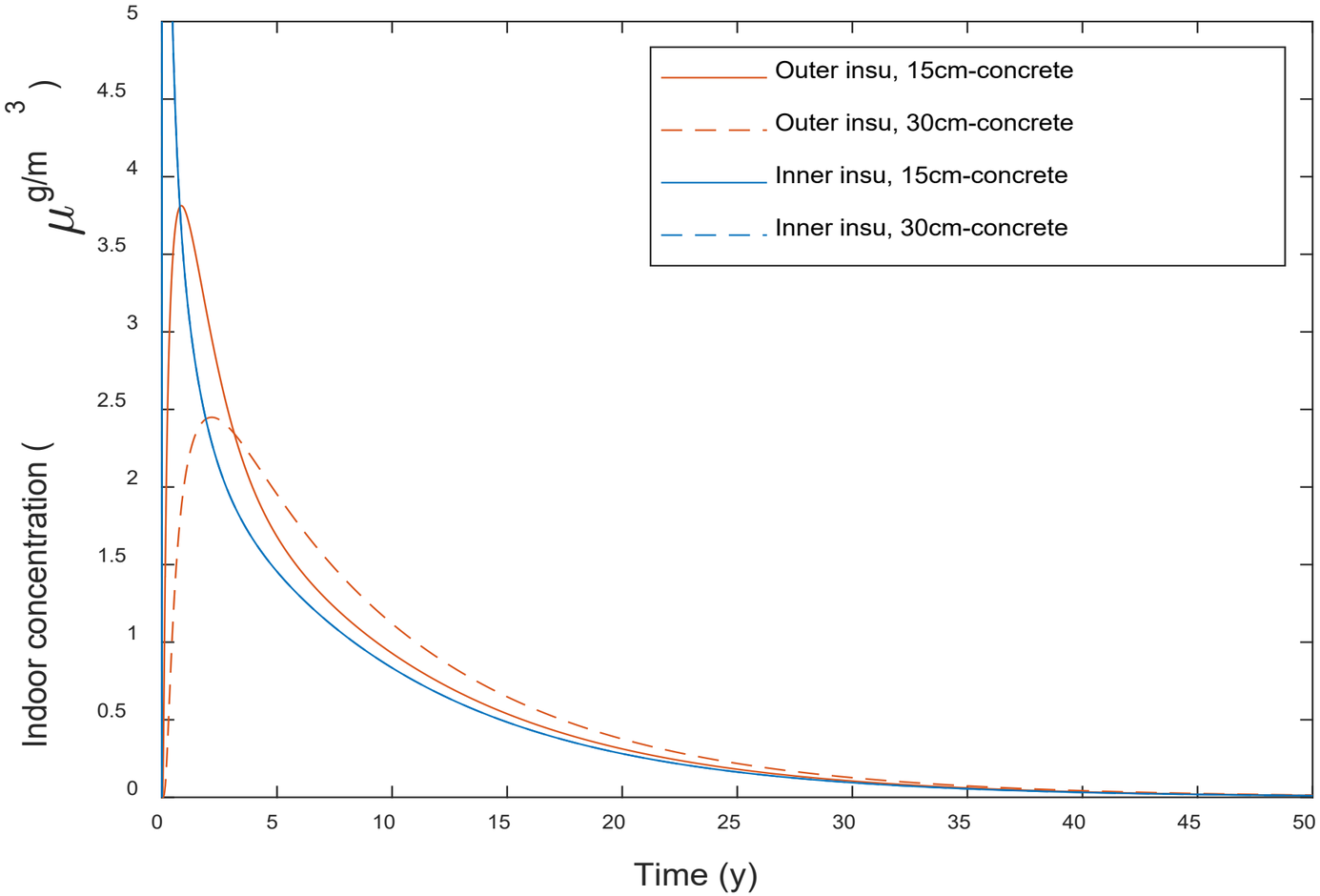


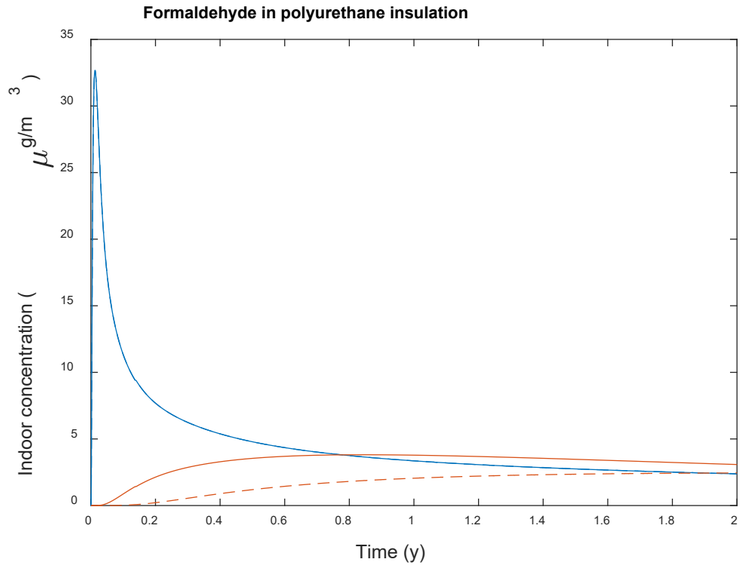




100% emitted after 50years for every insulation system

WHAT MATTERS FOR INDOOR EXPOSURE? Surprisingly, not the position of the insulation inner/outer for VOCs, nor the thickness of the concrete layer





Inner insulation:

PiF = 0.20%

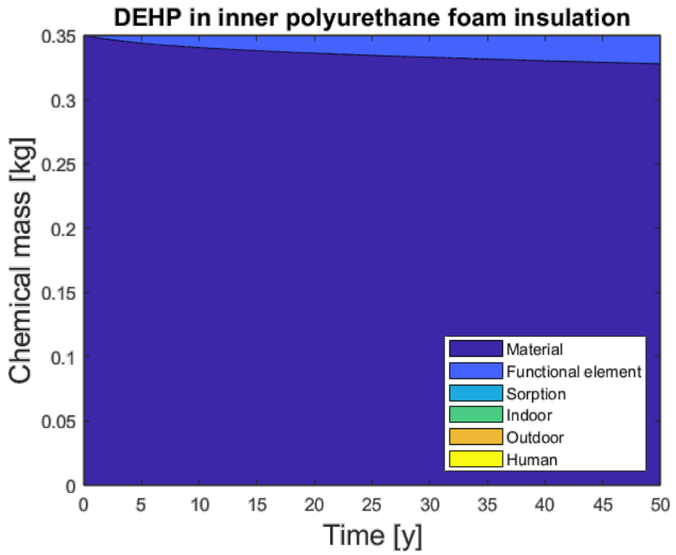
Human health damage= 0.0041 DALY

Outer insulation:

PiF = 0.20%

Human health damage= 0.0041 DALY

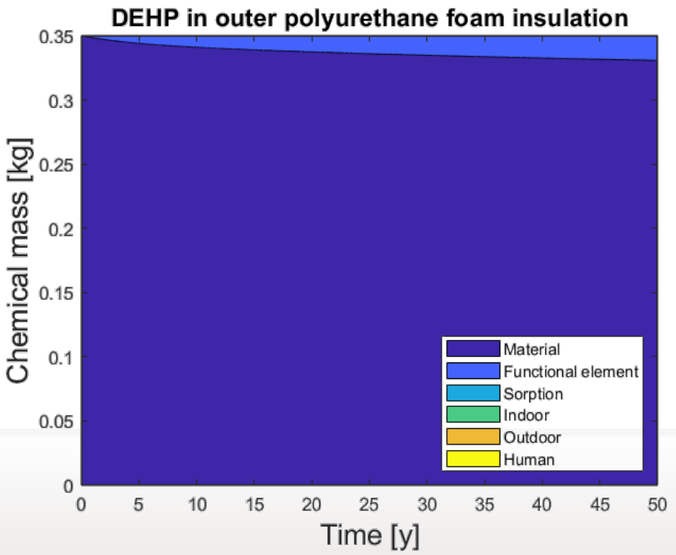
RESULTS: WHAT MATTERS FOR INDOOR EXPOSURE?
Large influence of insulation position for SVOCs such as DEHP!



Inner insulation:

PiF = $3.86e^{-7}$ $kg_{intake}/kg_{initial}$

Human health damage= $8.8e^{-7}$ DALY



Outer insulation:

PiF = $9.91e^{-10}$ $kg_{intake}/kg_{initial}$

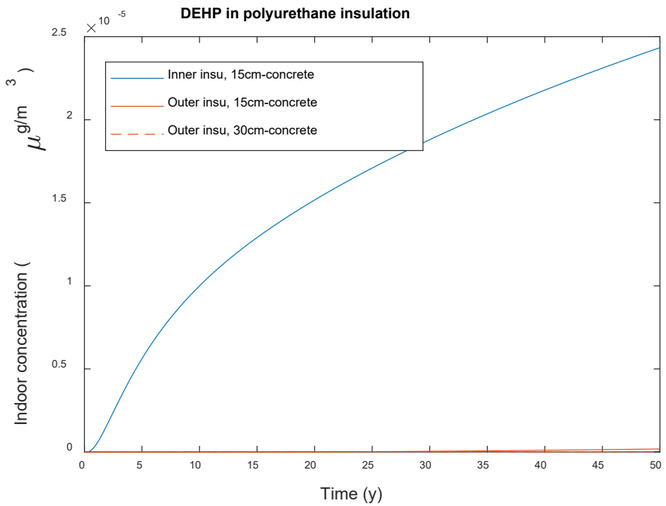
Human health damage= $1.3e^{-9}$ DALY

Outer insulation with 30cm-concrete:

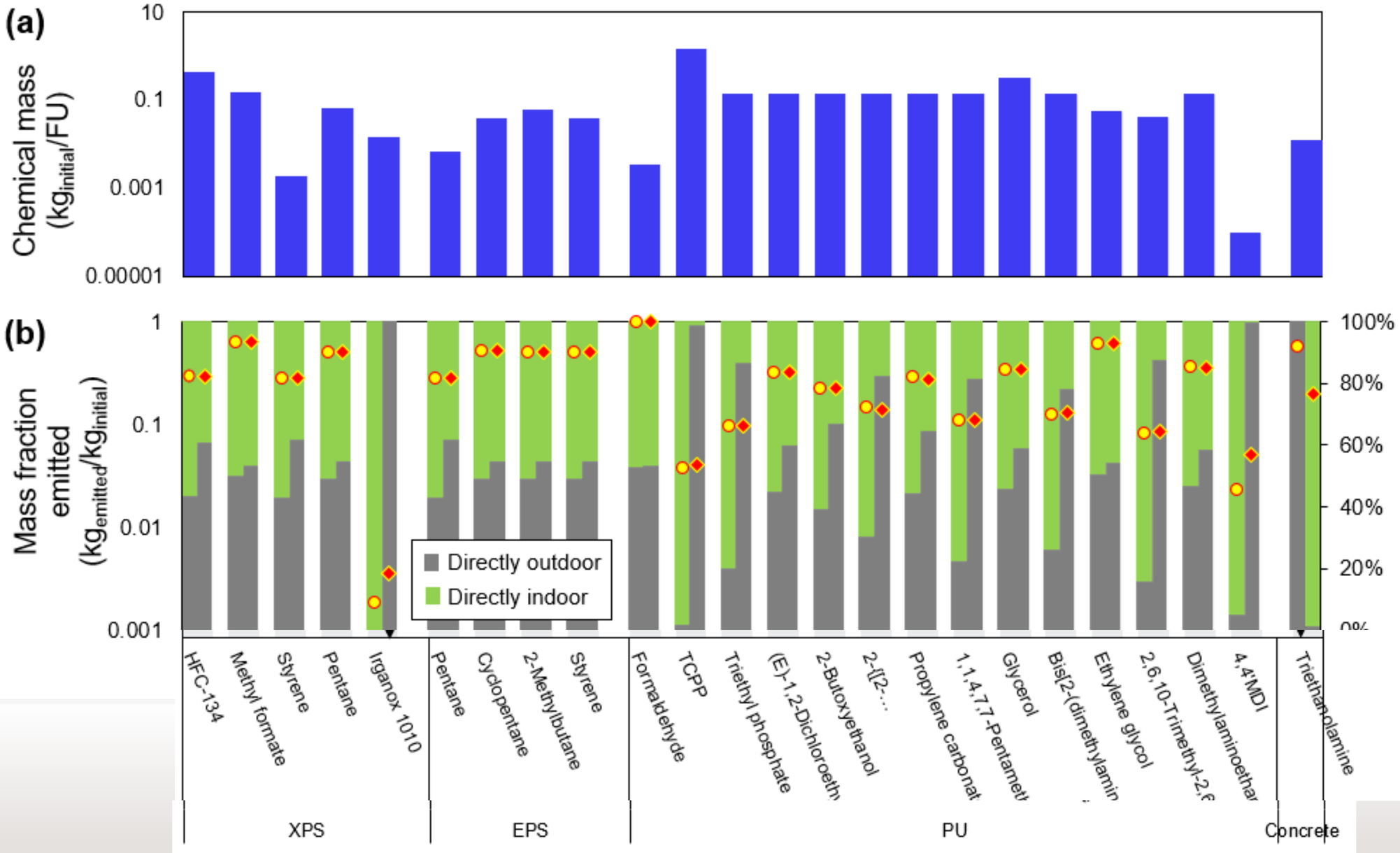
PiF = $9.40e^{-12}$ $kg_{intake}/kg_{initial}$

Human health damage= $7.0e^{-14}$ DALY

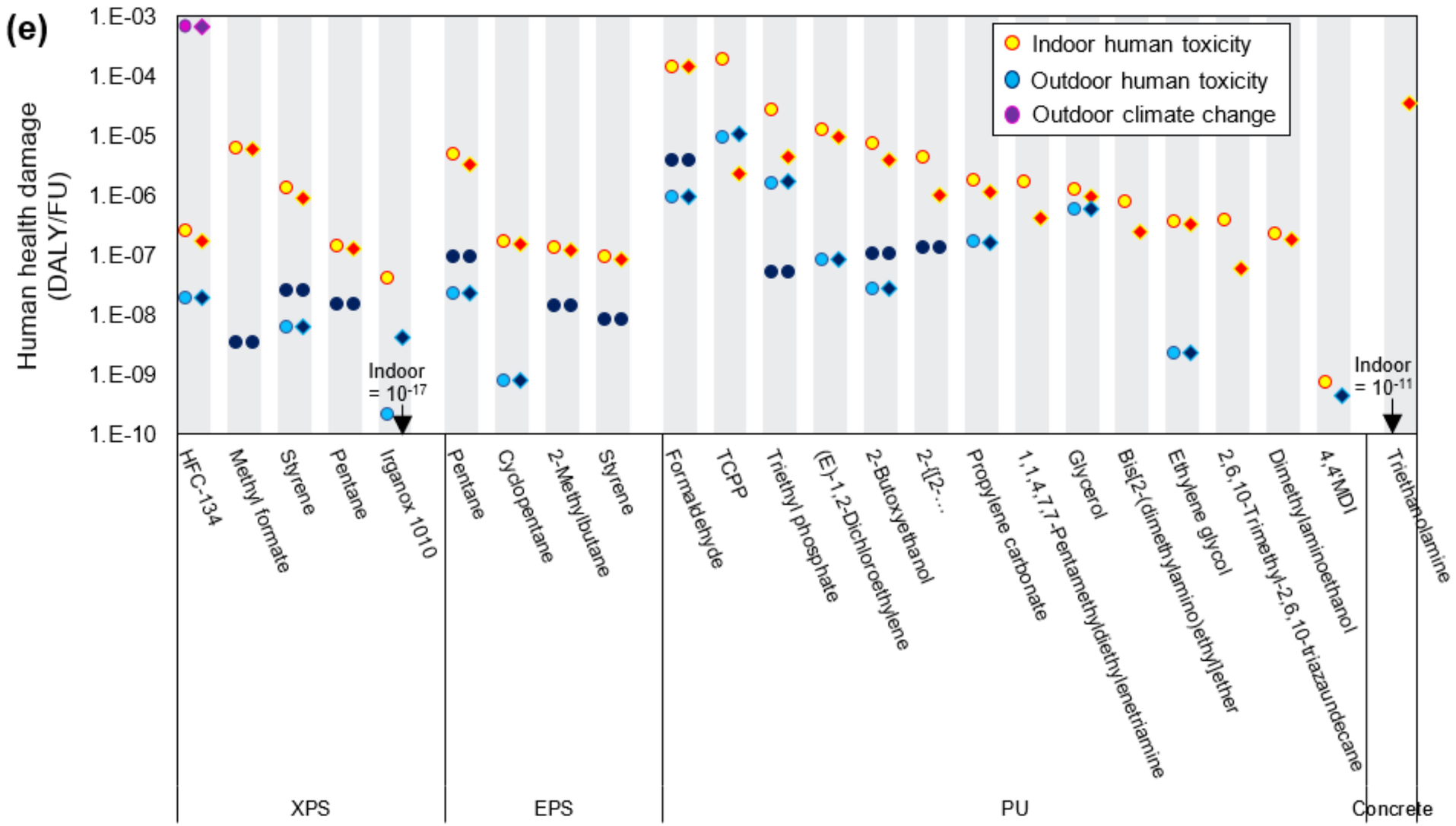
0.01%, and 0.04% emitted after 50years for inner and outer insulation respectively



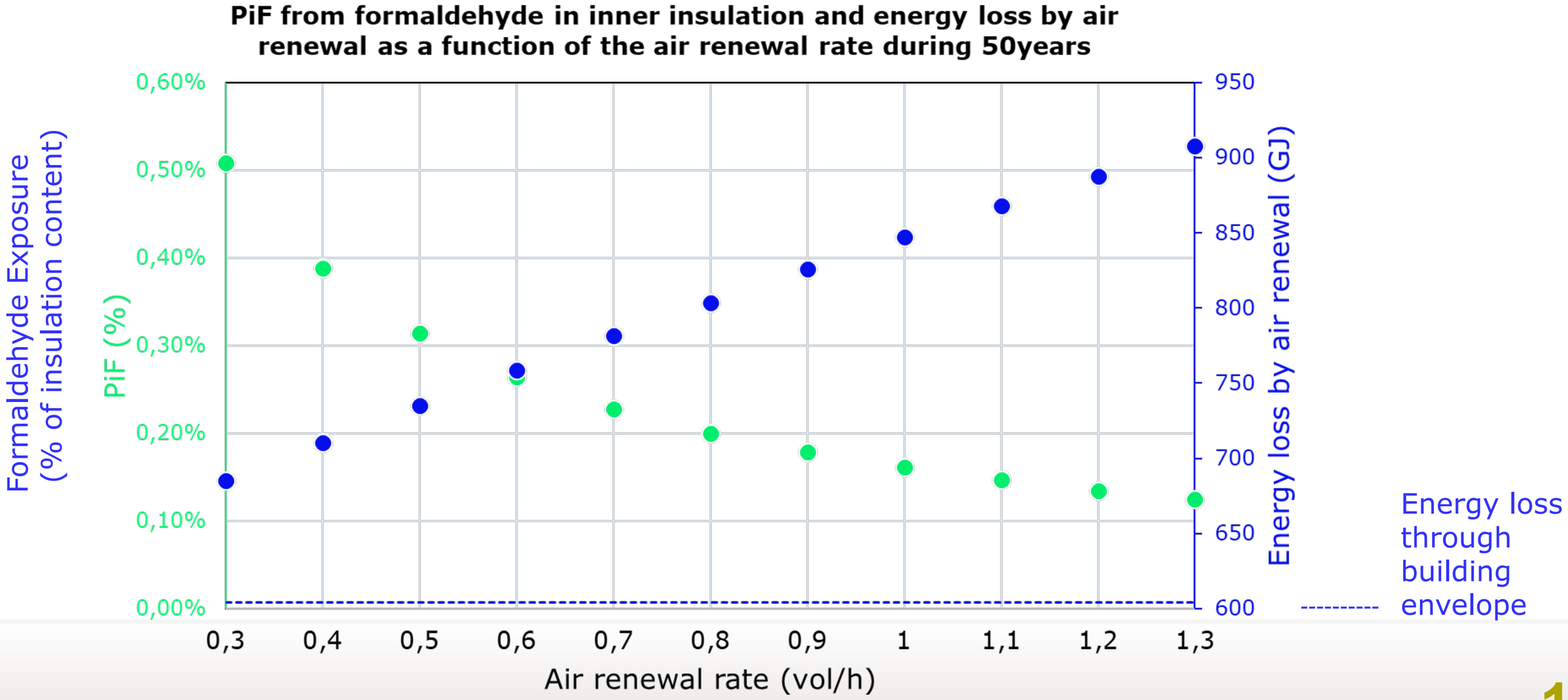
Releases: (a) Initial chemicals mass/m2 and mass fraction emitted directly indoor (green) and directly outdoor (grey) for inner (circle) & outer (diamond) insulation



Resulting Human health damage during use phase

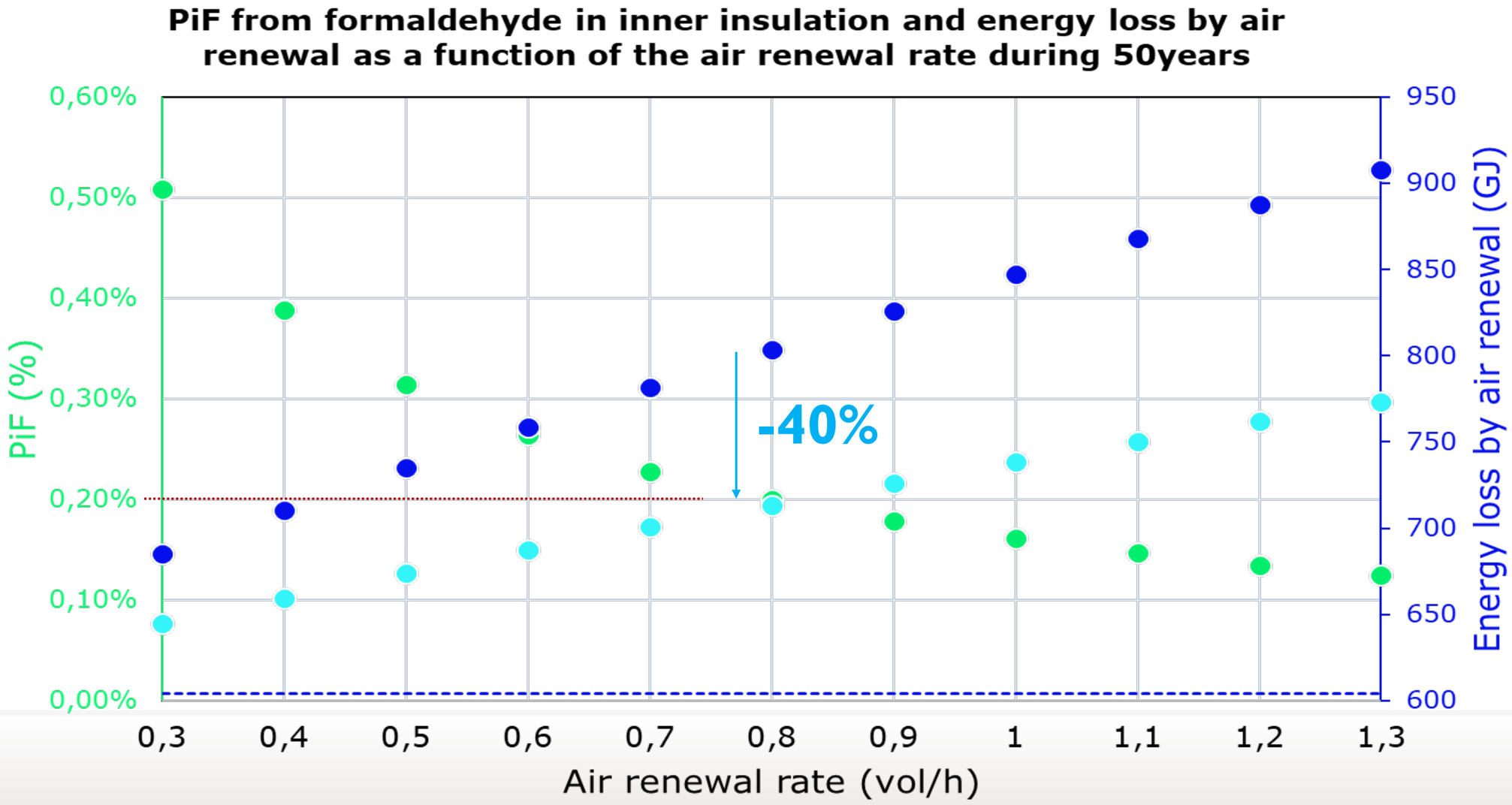


SHIFTING THE BURDEN FROM ENERGY EFFICIENCY TO INDOOR POLLUTION
Air renewal rate: substantial trade-off



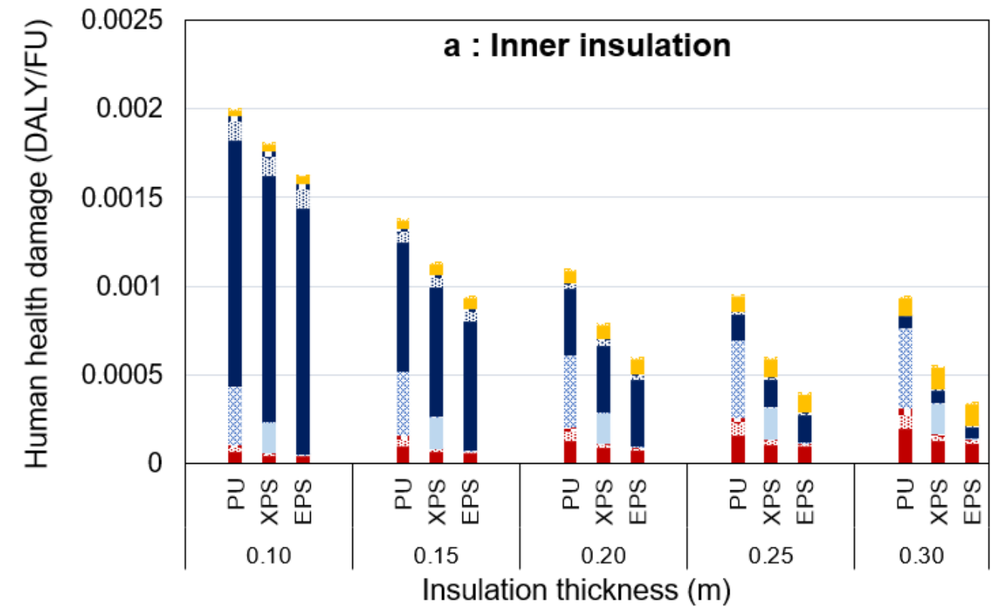
SHIFTING THE BURDEN FROM ENERGY EFFICIENCY TO INDOOR POLLUTION

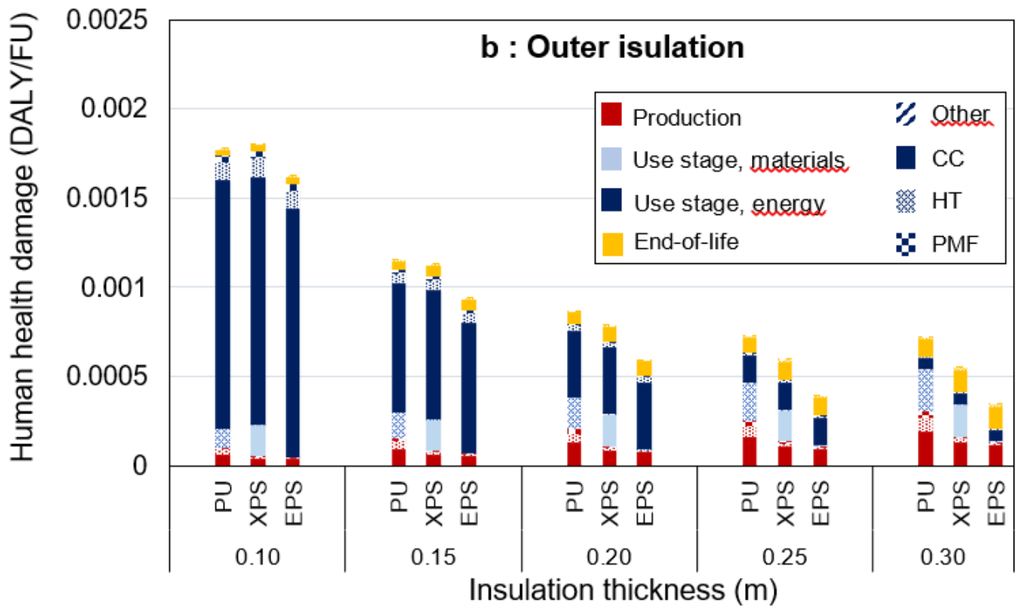
Air renewal rate: substantial trade-off – with heat exchanger

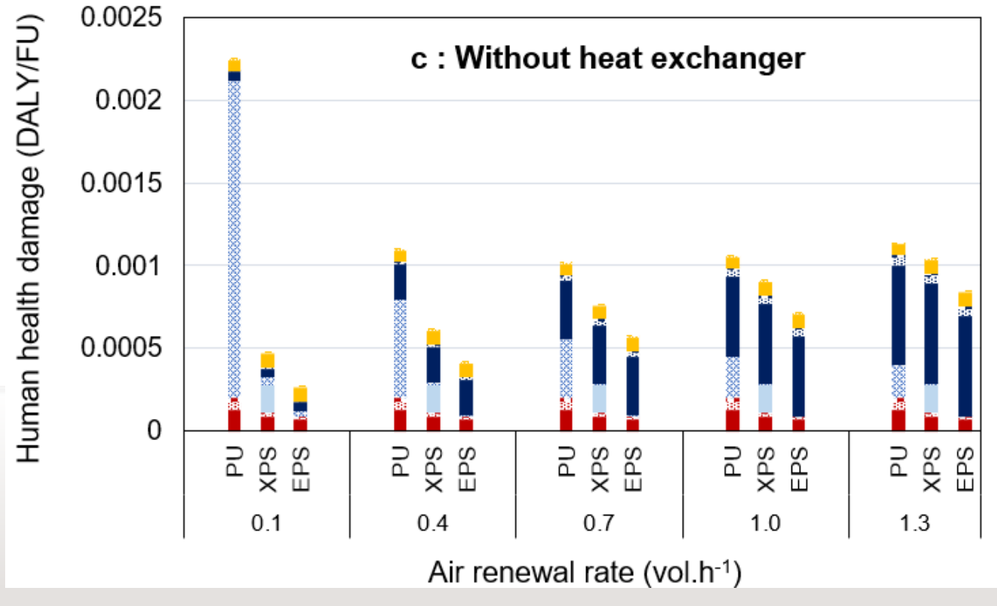


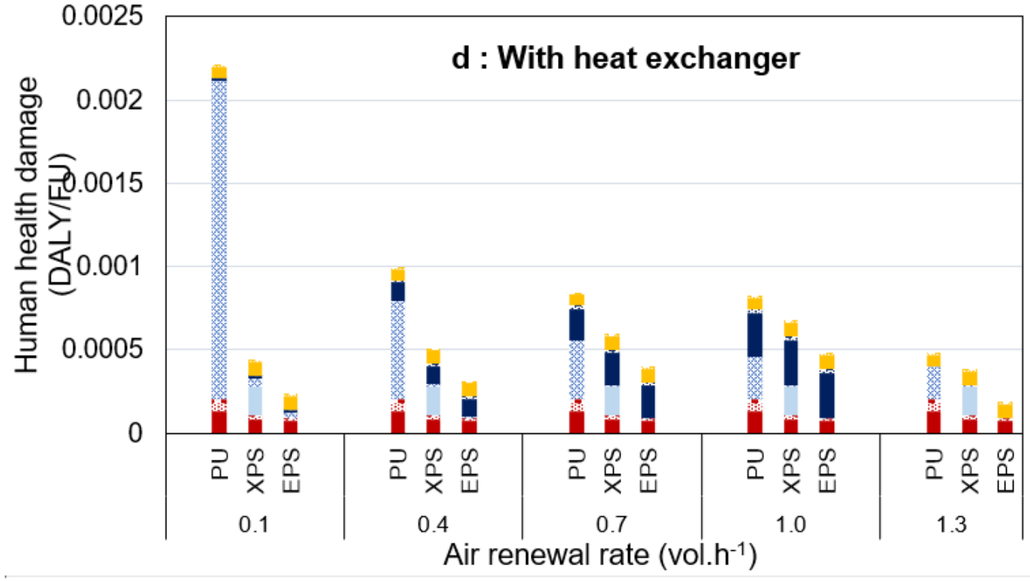
For the same indoor exposure standard, the heat exchanger allows to reduce energy losses

Trade-off - insulation-health: Life cycle human health damage as a function of insulation thickness and air renewal for inner (a) and outer (b) without (c) & with (d) heat exchanger









USEtox® – the UNEP-SETAC toxicity consensus model

USEtox base model + six basic models applied to 10000 chemicals in 500 products

→ customized to particular applications + developed necessary QSARS for high throughput determination

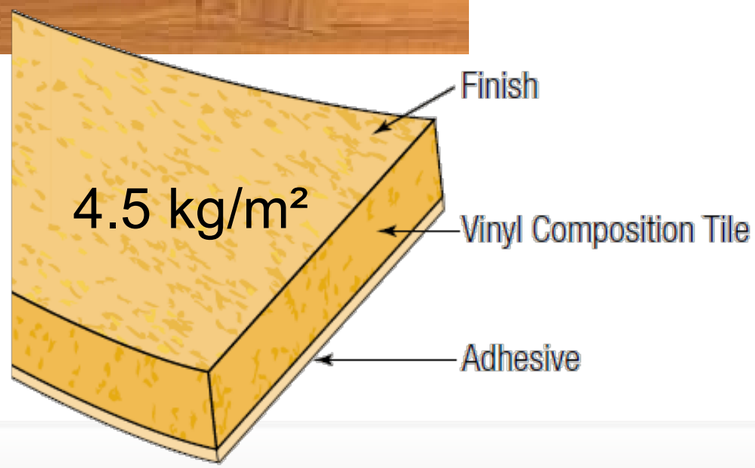
→ Relevant mass balance-based models for building and materials:

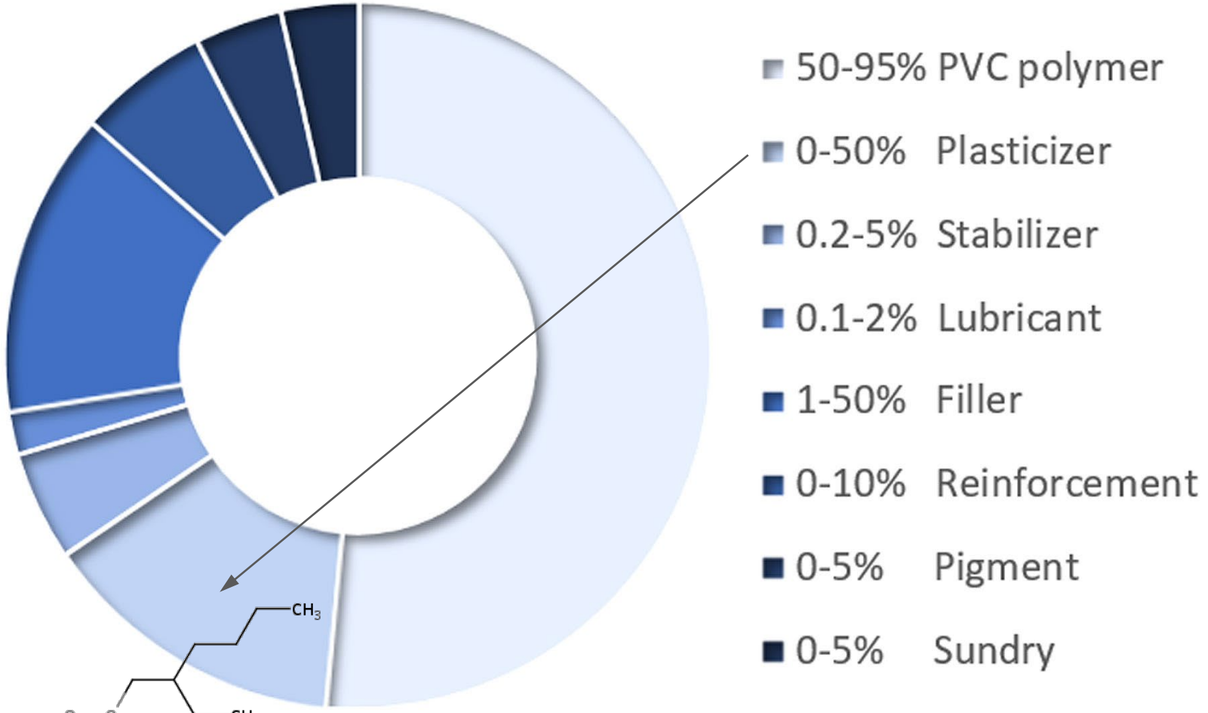
- Releases from **building materials**, *with indoor sorption)*
- Releases from **object surface** (e.g. wet **paints**, cleaning agents)
- Indoor air modeling

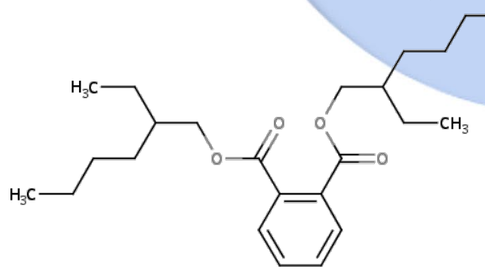
→ USEtox determines

- Human exposures of the user and the general population via inhalation, ingestion incl. mouthing and dust , dermal direct contact and gaseous uptake
- Risks for cancer, developmental and other non-cancer
  Maximum chemical content for acceptable risk
  Cumulative human health and ecosystem impacts for LCA

Substituting DEHP in Vinyl Flooring



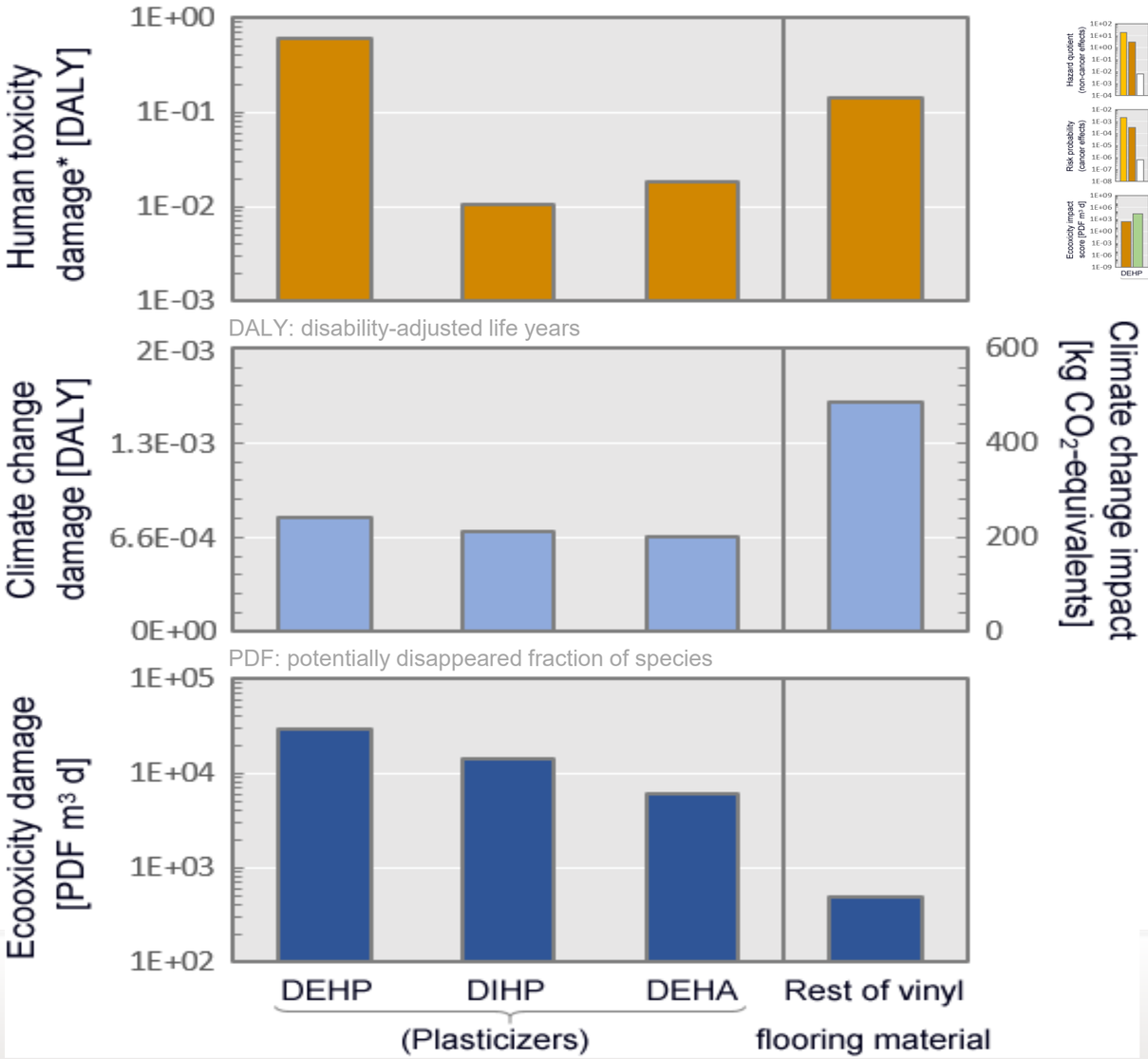


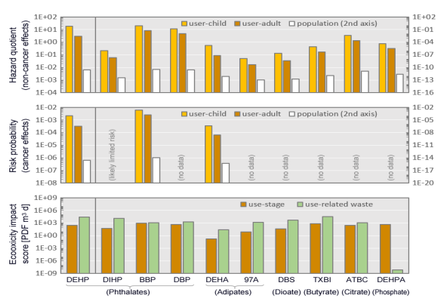


Di(2-ethylhexyl) phthalate (DEHP)
CAS RN: 117-81-7

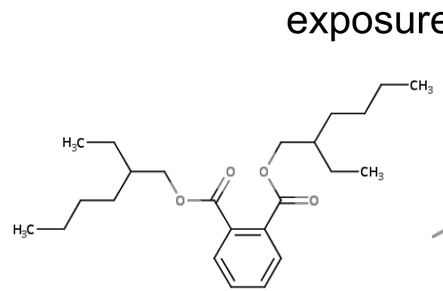
Fantke et al., 2020, Green Chemistry. 22 (18), 6008-6024 (https://doi.org/10.1039/d0gc01544j).

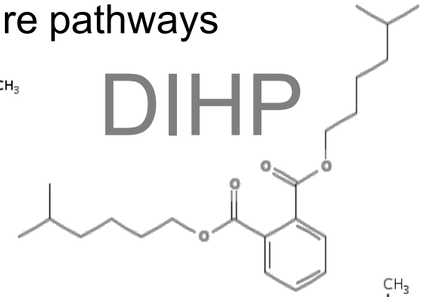
Substituting DEHP phthalate in flooring

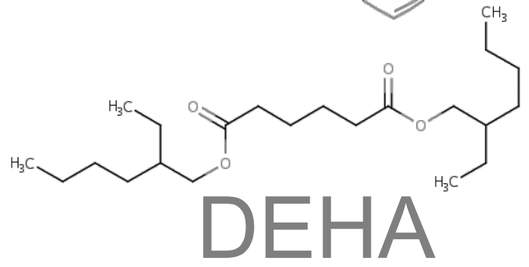




- Screen alternatives
- Impacts beyond use-stage risks: depends on chemical function and product appliation
- **Chemical function** determines weight fraction and risk potency
- **Product application** determines main direct exposure pathways







- Impacts brought to **damage level** for highest possible aggregation and evaluation of potential trade-offs

High throughput screening of chemicals in building materials

Journal of Hazardous Materials 424 (2022) 127574

Contents lists available at ScienceDirect

Journal of Hazardous Materials

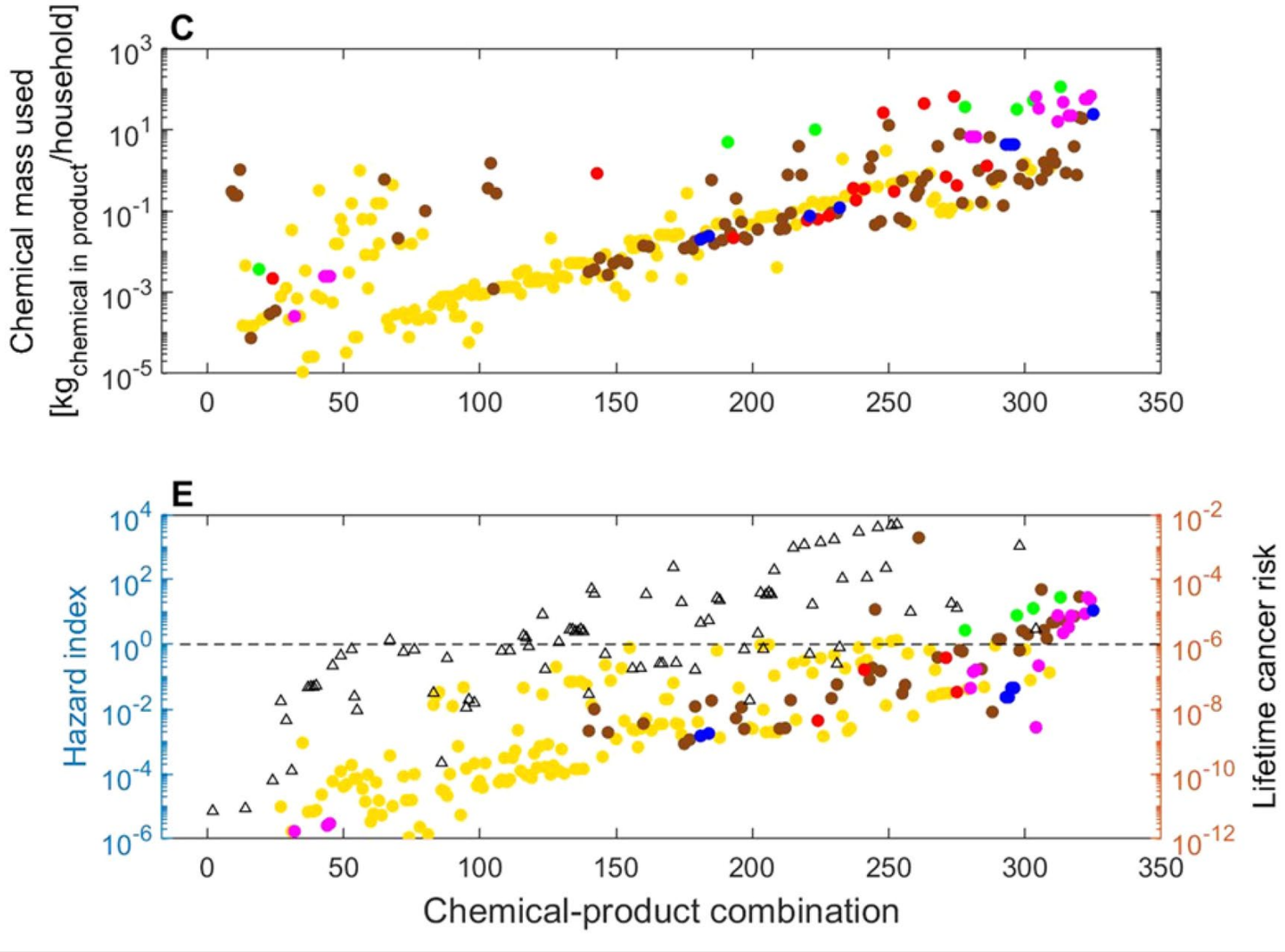
journal homepage: www.elsevier.com/locate/jhazmat

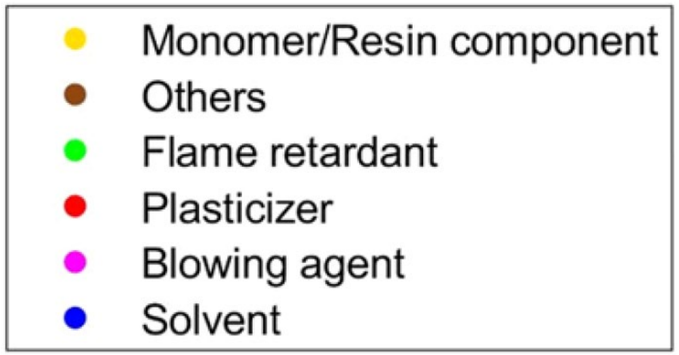
Chemicals of concern in building materials: A high-throughput screening

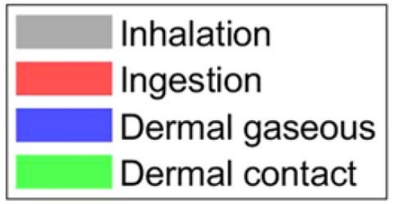
Lei Huang [a], Peter Fantke [b], Amélie Ritscher [c], Olivier Jolliet [a,b,*]

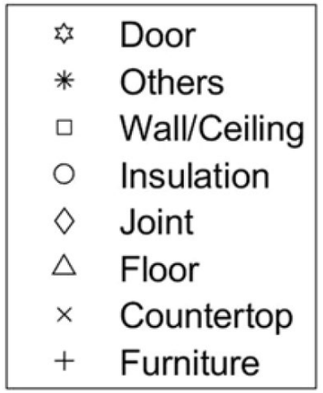
Huang et al., 2021. https://doi.org/10.1016/j.jhazmat.2021.127574

Chemical mass used and related hazard of 325 chemicals in buildings









Chemicals of concern in building materials

5

CAS	Chemical	Product categories*	Chemical function	MAC (ppm)	MAC endpoint	Actual content (ppm)	HCR
822-06-0	1,6-Hexamethylene diisocyanate (HDI)	Carpet flooring	Crosslinker	0.2	Non-cancer	48800	244000
		Acrylic flooring adhesive	Crosslinker	7	Non-cancer	13650	1950
		Flooring (wood, cork, vinyl)	Crosslinker, Residual monomer	0.1	Non-cancer	2.8 - 236	28 - 2360
51-79-6	Ethyl carbamate	Flooring (rubber, cork, wood)	Solvent	0.2	Cancer	11560 - 28800	57800 - 144000
50-00-0	Formaldehyde	Wooden furniture, Base cabinetry	Preservative, Residual monomer	0.1	Cancer	6.6 - 3102	110 - 51700
		Flooring (wood, cork, bamboo, fluid-applied)	Preservative, Residual monomer	0.1	Cancer	6.58 - 1890	94 - 27000
		Gypsum wallboard	Preservative	0.03	Cancer	1032	34400
		Foam insulation (polyurethane, spray), Gypsum ceiling	Preservative, Residual monomer	0.1	Cancer	2.8 - 236.8	35 - 2960

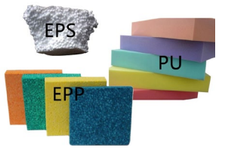
Chemicals of concern in building materials

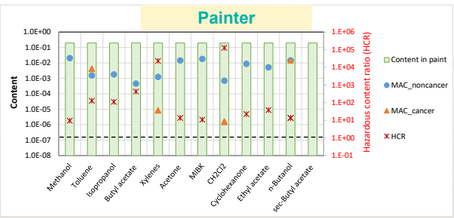
5

101-68-8	Methylene bisphenyl diisocyanate (MDI)	Flooring (rubber, carpet, fluid-applied, wood)	Unknown	10	Non-cancer	610 - 40500	61 - 4050	IPD
		Wooden furniture	Unknown	20	Non-cancer	78400	3920	
151-56-4	Ethyleneimine (Aziridine)	Flooring (wood, cork), Wooden furniture	Residual monomer	0.02	Cancer	3.94 - 63.2	197 - 3160	IPD
102-71-6	Triethanolamine (TEA)	Concrete mansory unit	Water reducer	0.02	Cancer	25	1250	CPD
25013-16-5	Butylated hydroxyanisole (BHA)	Carpet flooring	Antioxidant	6	Cancer	5202	867	IPD
111-76-2	Ethylene glycol monobutyl ether (EGBE)	Cork flooring	Solvent	50	Cancer	39600	792	IPD
		Polyurethane foam insulation	Solvent	200	Cancer	11600	58	
872-50-4	N-Methyl-2-pyrrolidone (NMP)	Flooring (wood, cork)	Solvent	10	Cancer	3050 - 6920	305 - 692	IPD
85-68-7	Butyl benzyl phthalate (BBP)	Flooring (vinyl, carpet)	Plasticizer	60	Cancer	12480 - 41400	208 - 690	CPD+IPD
		Elastic facade joint sealant	Plasticizer	10000	Cancer	150000	15	
75-01-4	Vinyl chloride	Flooring (carpet, vinyl, VCT)	Residual monomer	1	Cancer	0.36 - 241.2	0.6 - 402	CPD+IPD
		Polyurethane Foam Insulation	Residual monomer	1	Cancer	1.2 - 11.4	2 - 19	
124-09-4	1,6-Hexanediamine	Carpet flooring	Unknown	300	Non-cancer	114000	380	IPD
111-46-6	Diethylene glycol (DEG)	Polyurethane Foam Insulation	Solvent	50	Cancer	15200	304	IPD
		Gypsum Ceiling	Solvent	20	Cancer	4720	236	
100-42-5	Styrene	Insulation (XPS, EPS, PS foam)	Residual monomer	10	Cancer	3.7 - 2990	0.37 - 299	CPD+IPD

Summary – chemical in building materials

- Absolute sustainable buildings requires high reduction factors for operation, construction and background decarbonization
- Important trade-offs between energy efficiency and indoor air quality
- The developed coupled heat-chemical mass enables to study these trade-off and account for the moderate interaction with temperature
- High insulation provide important benefits: Outer insulation only reduces indoor exposure for SVOCs but NOT substantially for VOCs that can diffuse through concrete
- Air exchanger enables to reduce to the energy consumption for the same standard of indoor exposure
- USEtox model enables us to screen hundreds of chemcials in building materials and identify chemicals of concern (also for paints).
- Central to account for these different effects on a life cycle perspective





Acknowledgment

This work was supported by the Global Environment Facility (GEF) project ID 9771 on ‘Global Best Practices on Emerging Chemical Policy Issues of Concern under UN Environment’s Strategic Approach to International Chemicals Management (SAICM)’ (Grant no. S1-32GFL- 000632).

Quantitative screening of impacts in minutes per pers per day

1. Chemicals in buildings and consumer products

10,000s product chemicals combinations

80 min. lost/d

2. Outdoor & indoor exposure to $PM_{2.5}$

400,000-cell multimedia world model

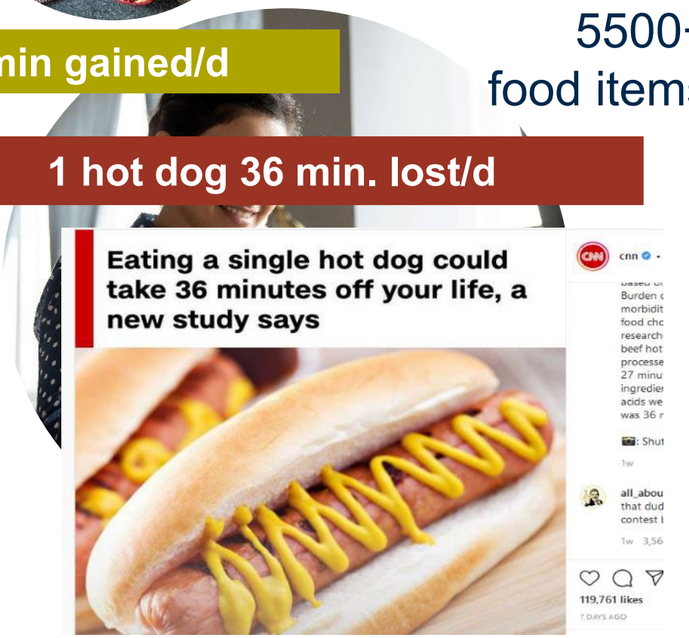
35 min. lost/d

3. Nutritional exposure

25 min gained/d

5500+ food items

1 hot dog 36 min. lost/d



5. Physical exercise

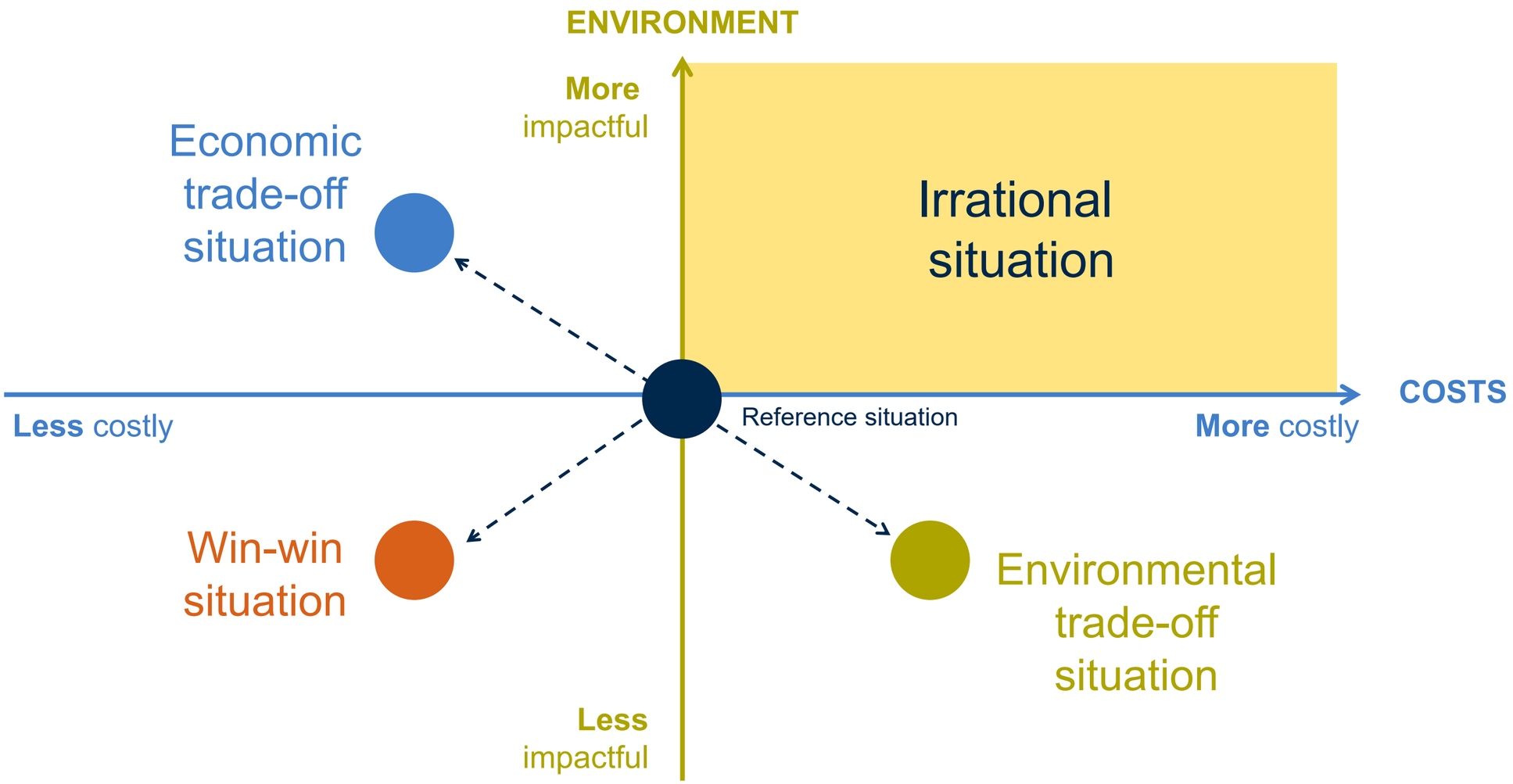
70 min. gained/d

5800+ foods - https://rdcu.be/cuVht

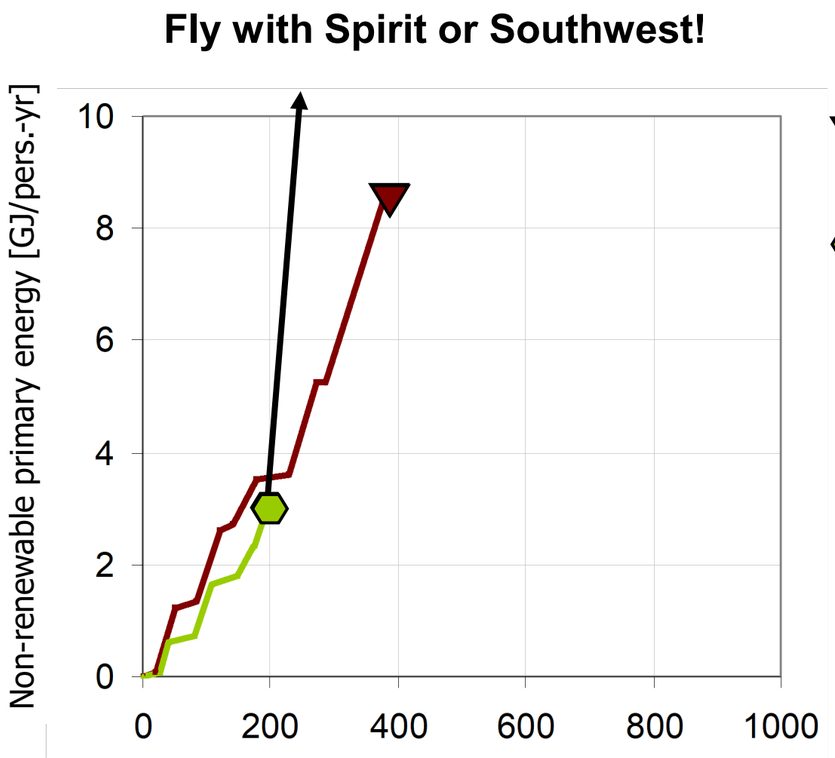
120,000 likes on CNN Instagram

An exciting era of Big Data, … for the ART OF COMPARING!

Assess changes: Life cycle Impacts vs Life Cycle Costs



Cumulated savings with energy star household appliances

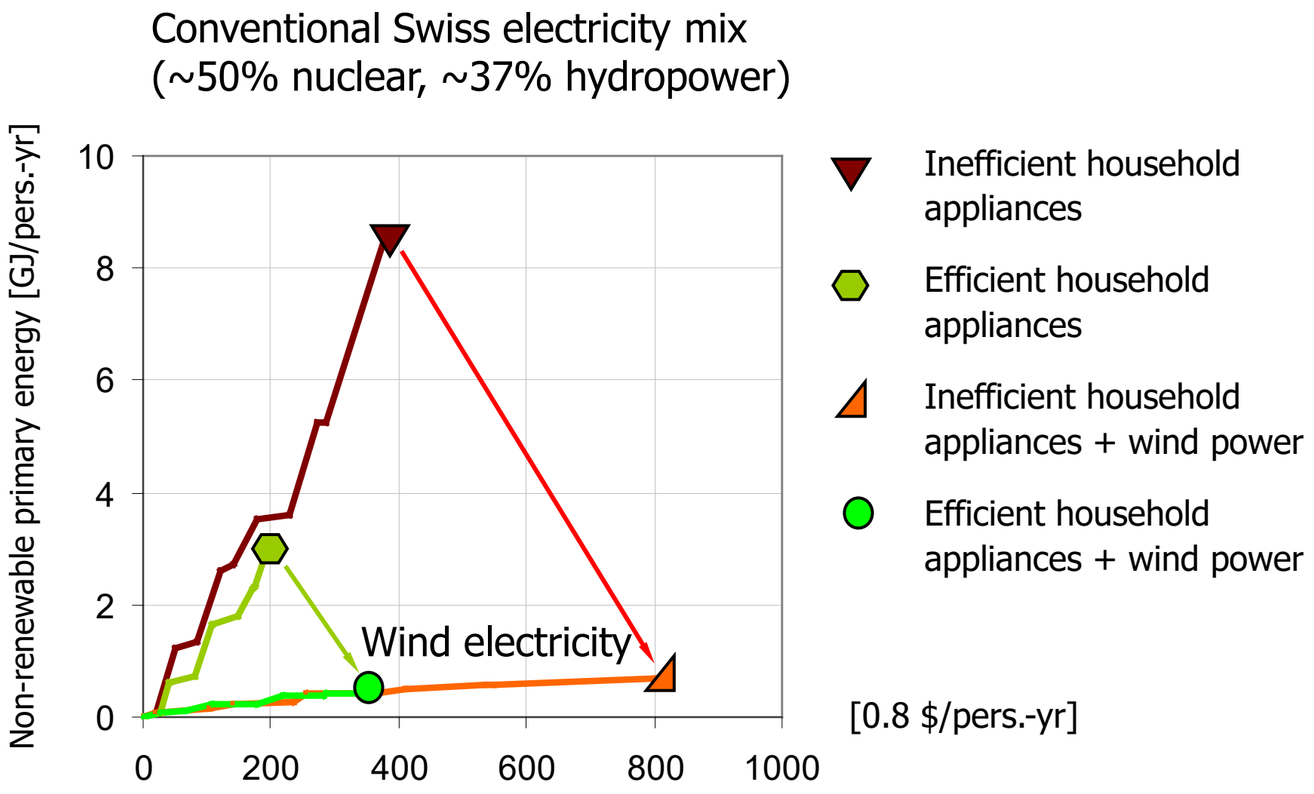


Unefficient household appliances

Efficient household appliances and drying the washing on the line

Savings: 5.5 GJ and $180 per person and year.

Savings with efficient household appliances and renewable energy

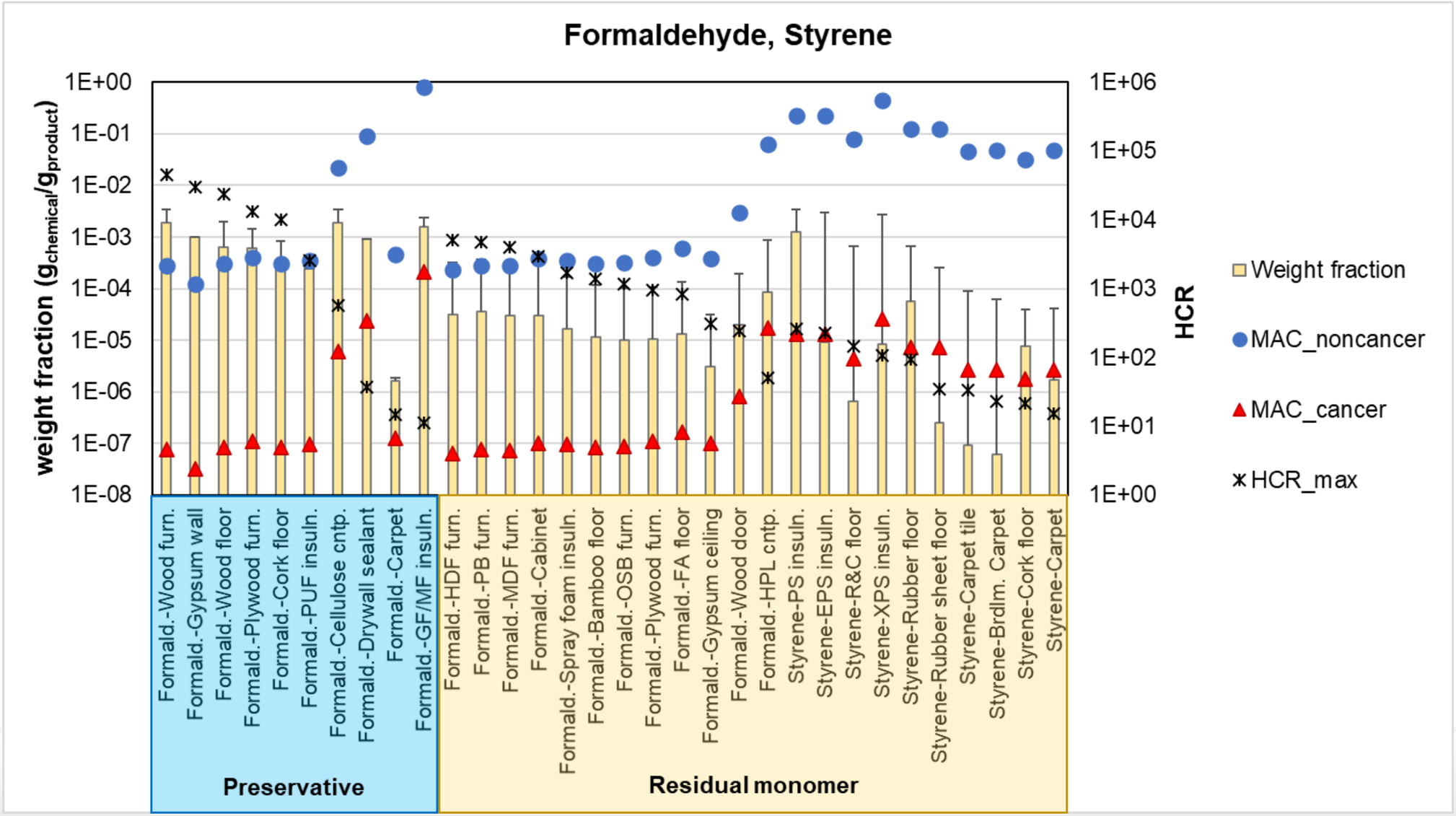


Save **$35** per person and year *or* pay **$420** per person and year.

Save energy first and then invest in renewable energy!

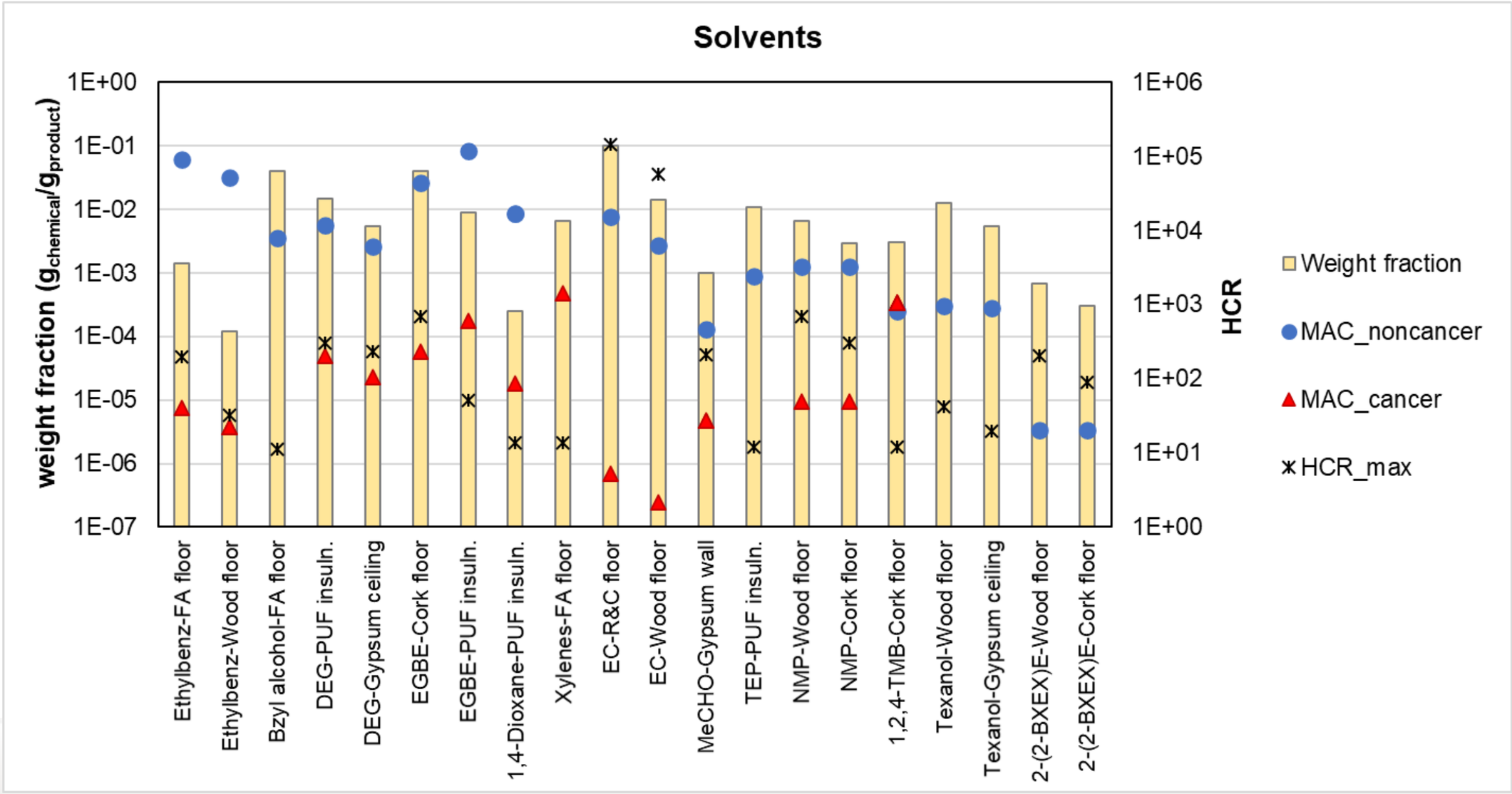
Identified Chemicals & Building Materials of Concern

5



Identified Chemicals & Building Materials of Concern

5



Main Application Areas of USEtox version 3

Near-field/far-field USEtox framework is suitable for **comparative evaluation of chemicals** emitted along product life cycles and chemicals in various product applications. Primary application areas are (model already tested):

Application area	Product types already covered in our framework (emissions already directly or indirectly included)
Product life cycle assessment (LCA)	Food contact materials
High-throughput exposure screening	Personal care products; food contact materials
High-throughput risk screening	Children toys; building materials; paints
Chemical exposure and risk prioritization	Household products (cleaning, personal care, and home maintenance products)
Chemical alternatives assessment (CAA) / chemical substitution	Building materials; personal care products; agricultural pesticides

http://doi.org/10.1007/s11367-021-01889-y