CHEM-EV01: Re-imagining Wood Waste | 8th November 2021

Wood in sustainable construction: approaches to enhancing materials- and energy-efficiency

Mark Hughes

Department of Bioproducts & Biosystems

Aalto University, Espoo, Finland

Today, I'd like to talk about three things:

1. Why wood in construction?
2. (How) can we harness the intrinsic properties of wood to best effect to reduce energy consumption and promote health and wellbeing?
3. How can we enhance the environmental sustainability of wood construction?

Part I: why?

The building sector is responsible for:

1.

Half of all extracted materials (50 Gt?)

The building sector is responsible for:

1.

Half of all extracted materials (50 Gt?)

2.

39% of CO_2 emissions

The building sector is responsible for:

1.

Half of all extracted materials (50 Gt?)

2.

39% of CO_2 emissions

3.

36% final energy use

Wood is:

- A good **structural** material
- **Renewable** (but not inexhaustible!)
- **Synthesised** from CO_2 and H_2O using solar energy + some other elements
- Naturally **biodegradable** (good and bad!)
- **Hydroscopic**
- A good thermal **insulator** and possesses a moderately high specific **heat capacity**
- Has pleasant **visual** and **tactile** properties….
- Etc… (you will find information about most of these topics in the slides/videos posted on My Courses)

Increasing wood use in buildings can contribute to sustainability through:

1.

Energy-efficiency and **health** benefits

2.

Carbon storage effect of wood products

3.

Substitution of energy-intensive materials

Increasing wood use in buildings can contribute to sustainability through:

1.

Energy-efficiency and **health** benefits

2.

Carbon storage effect of wood products

3.

Substitution of energy-intensive materials

Increasing wood use in buildings can contribute to sustainability through:

1.

Energy-efficiency and **health** benefits

2.

Carbon storage effect of wood products

3.

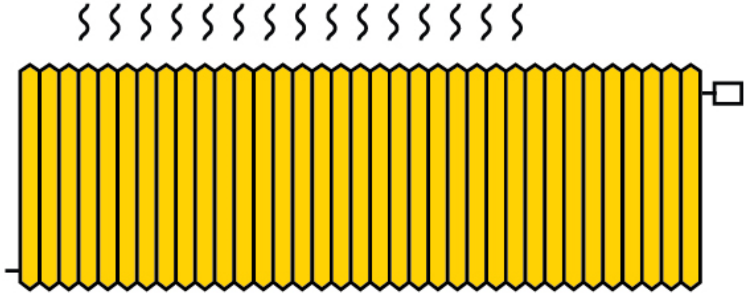
Substitution of energy-intensive materials

Part II: wood and energy-efficiency

What is the potential impact?

40%

In Finland, buildings represent around 40% of total energy consumption



70%

of energy use in residential housing accounted for space heating

- **Therefore small changes → big energy savings!**

The approach

Wood has under-exploited physical properties that can potentially help **passively** mediate a living environment and lead to both direct and indirect energy savings:

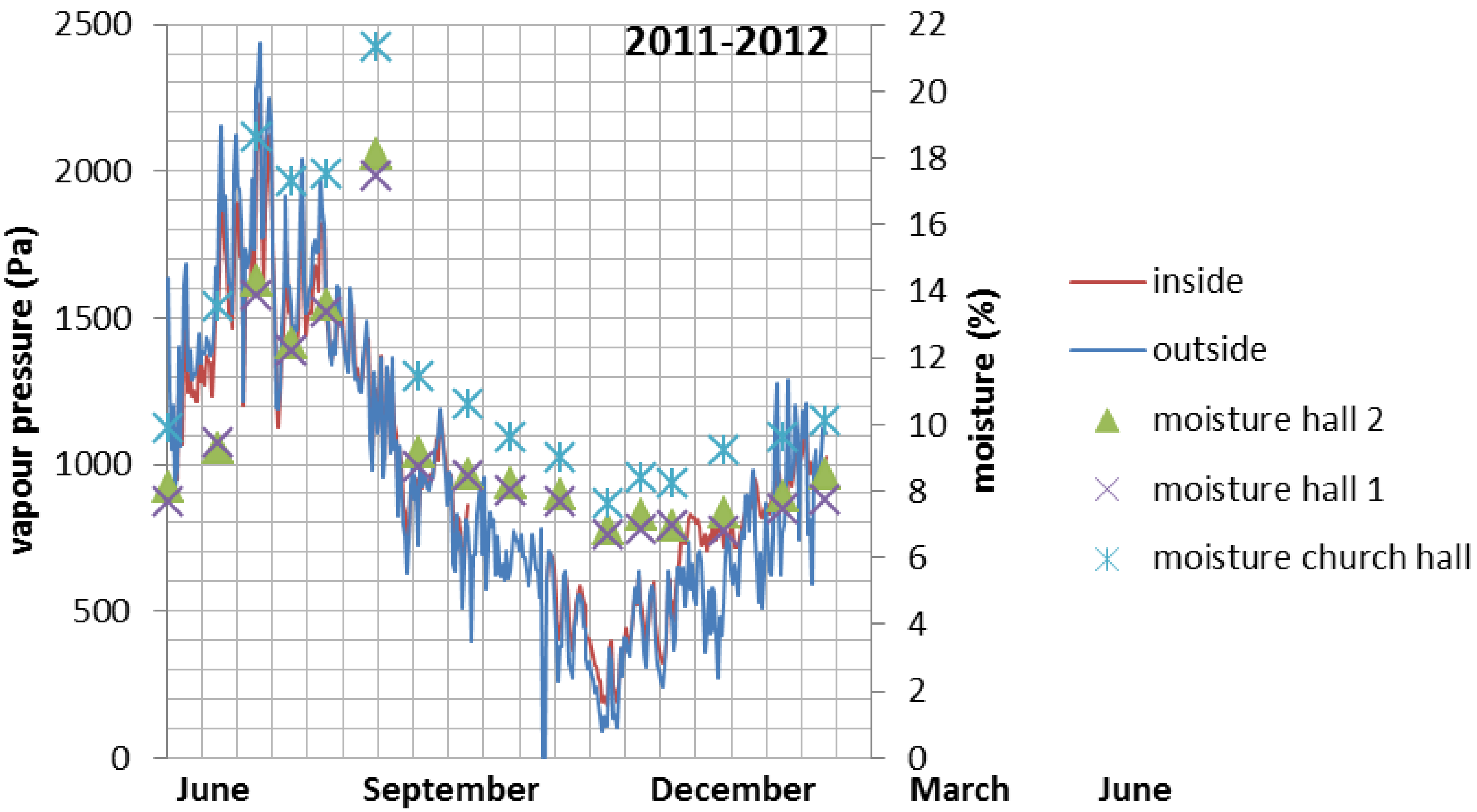
- Hygroscopicity leads to mass and heat flows
- Visual and tactile properties are influenced by underlying anatomy, chemistry and physical properties

So how?

- Firstly, we can exploit the **moisture** and **heat buffering** potential of wood as well as **latent heat** (heat of sorption) exchange possibilities
- Secondly, we can use the **visual** and **tactile** properties of wood and the **design** of an interior space to make people ‘**feel**’ warmer or more comfortable

Moisture buffering

The internal climate of a building



(Unpublished data from Viikki church, Helsinki)

Relative humidity & EMC

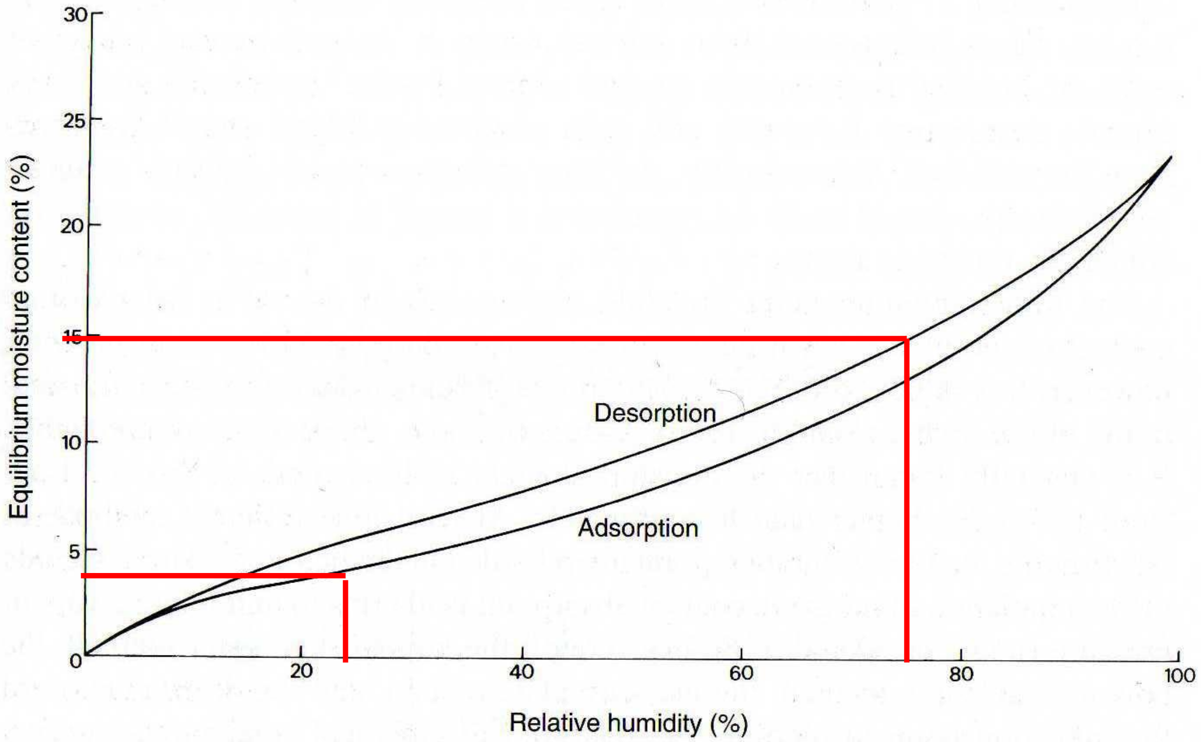
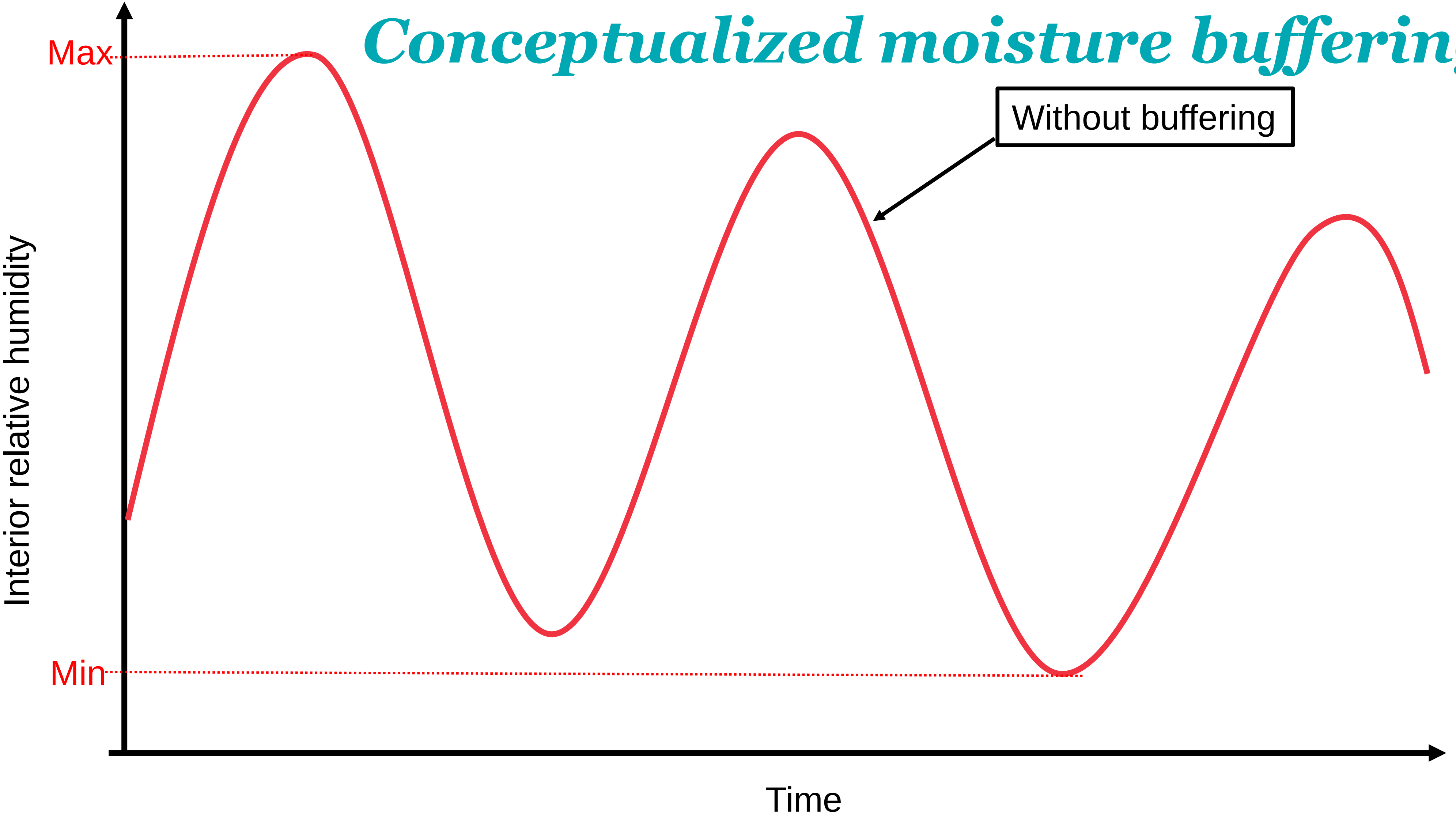
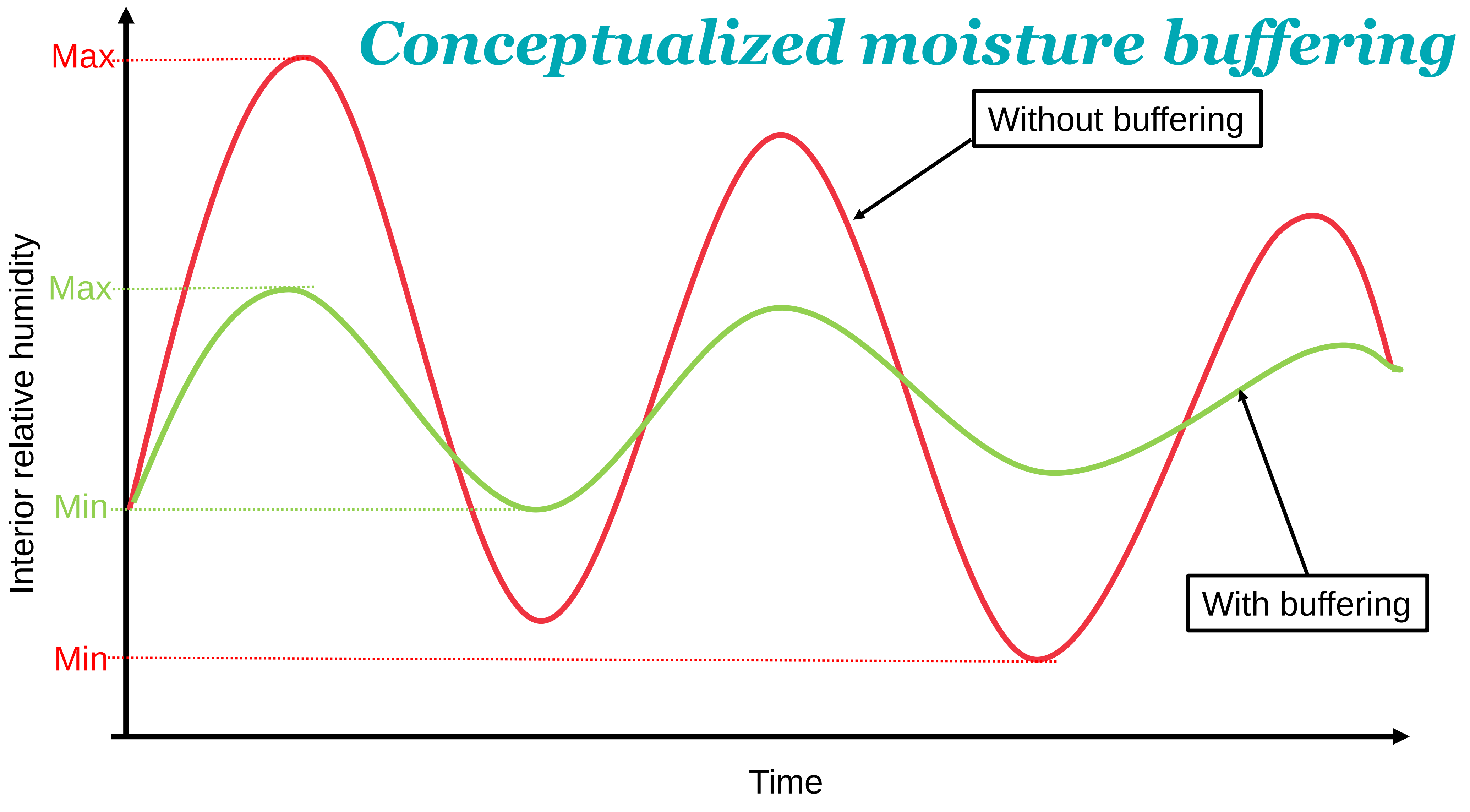


Figure 4.3 Hysteresis loop resulting from the average adsorption and desorption isotherms for six species of timber at 40 °C (©BRE.)

(Source: Dinwoodie, J.M. (2000). Timber: Its nature and behavior)

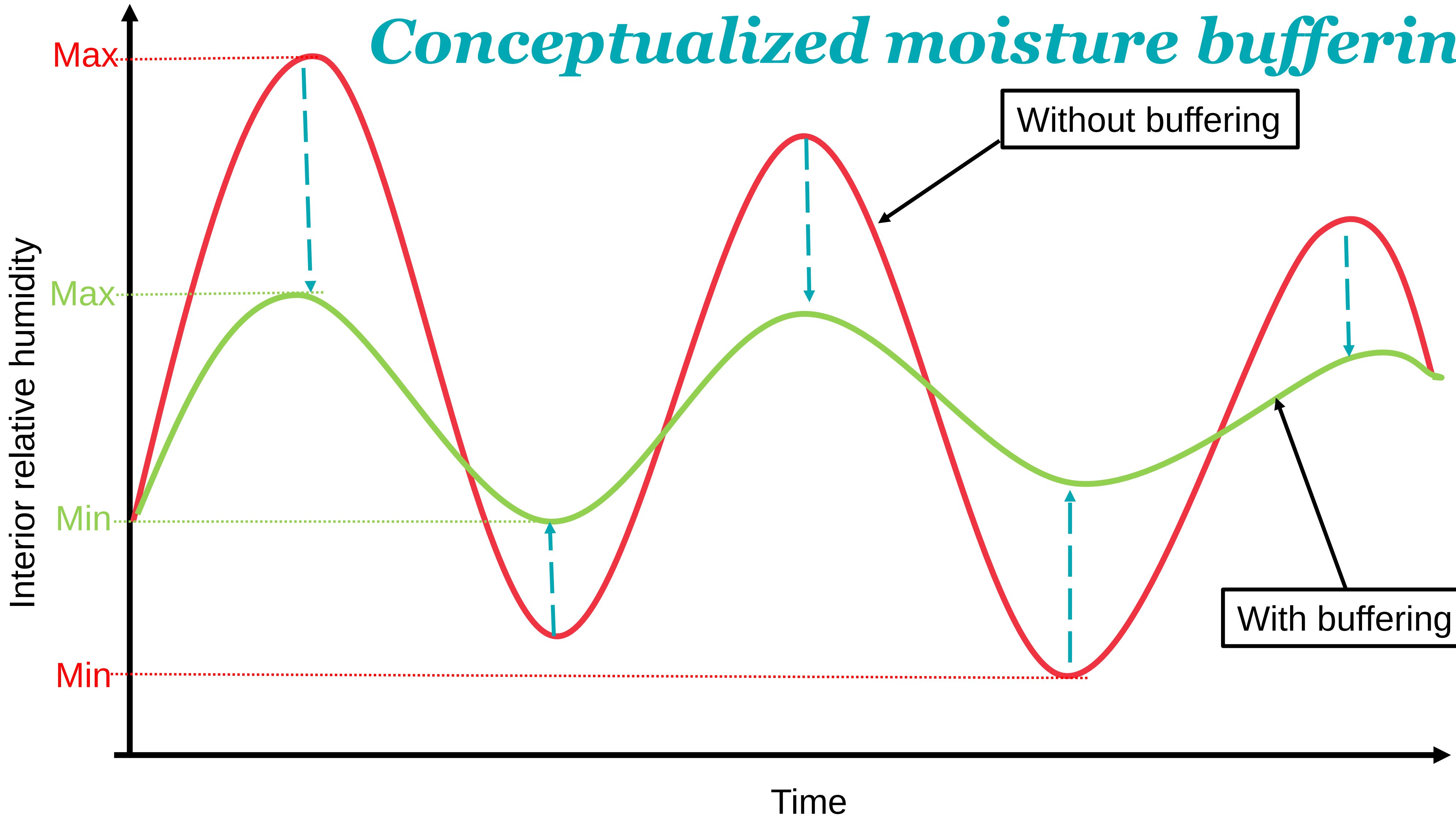
Conceptualized moisture buffering



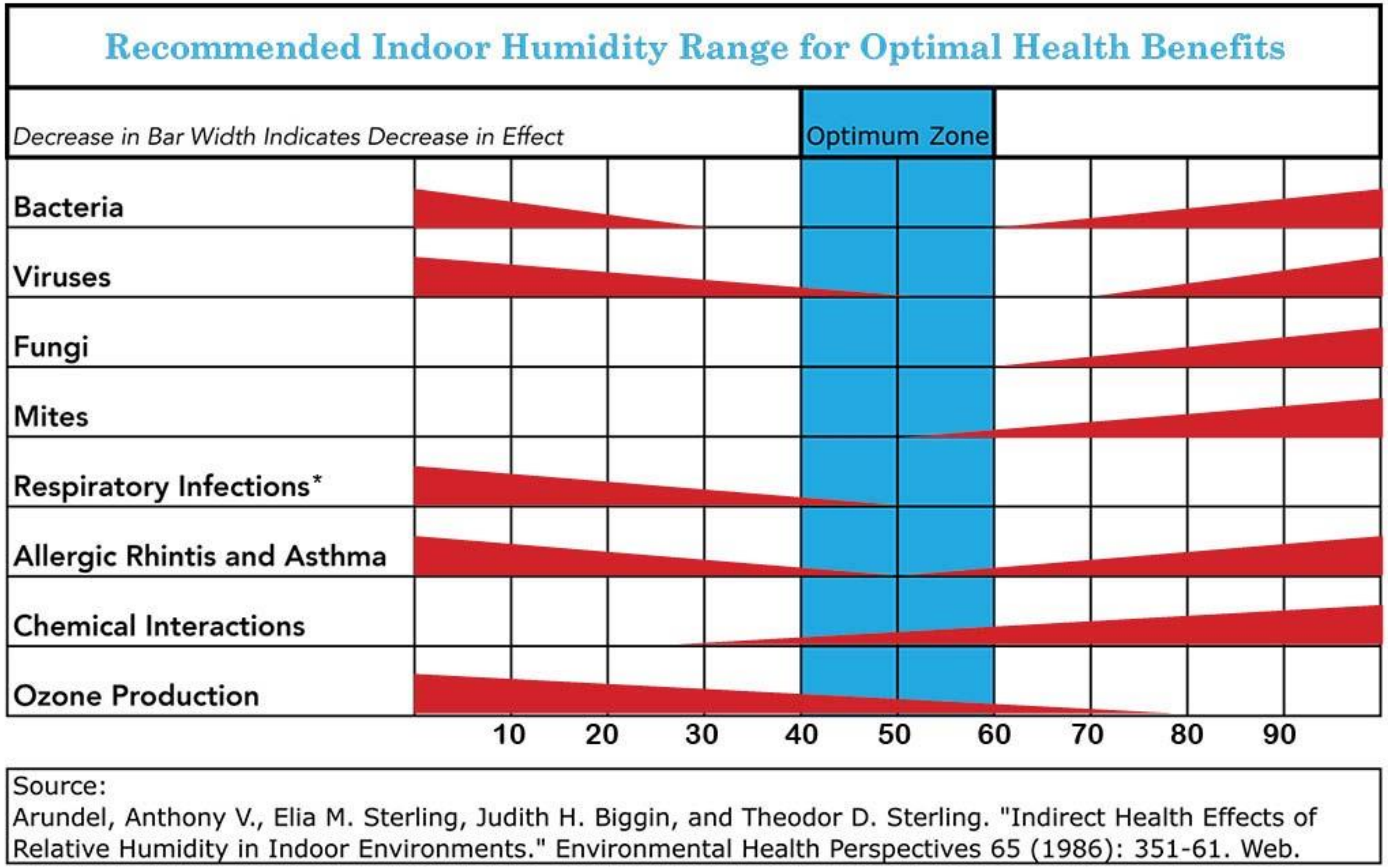


Conceptualized moisture buffering
Without buffering
With buffering
Max
Max
Min
Min
Interior relative humidity
Time

Conceptualized moisture buffering

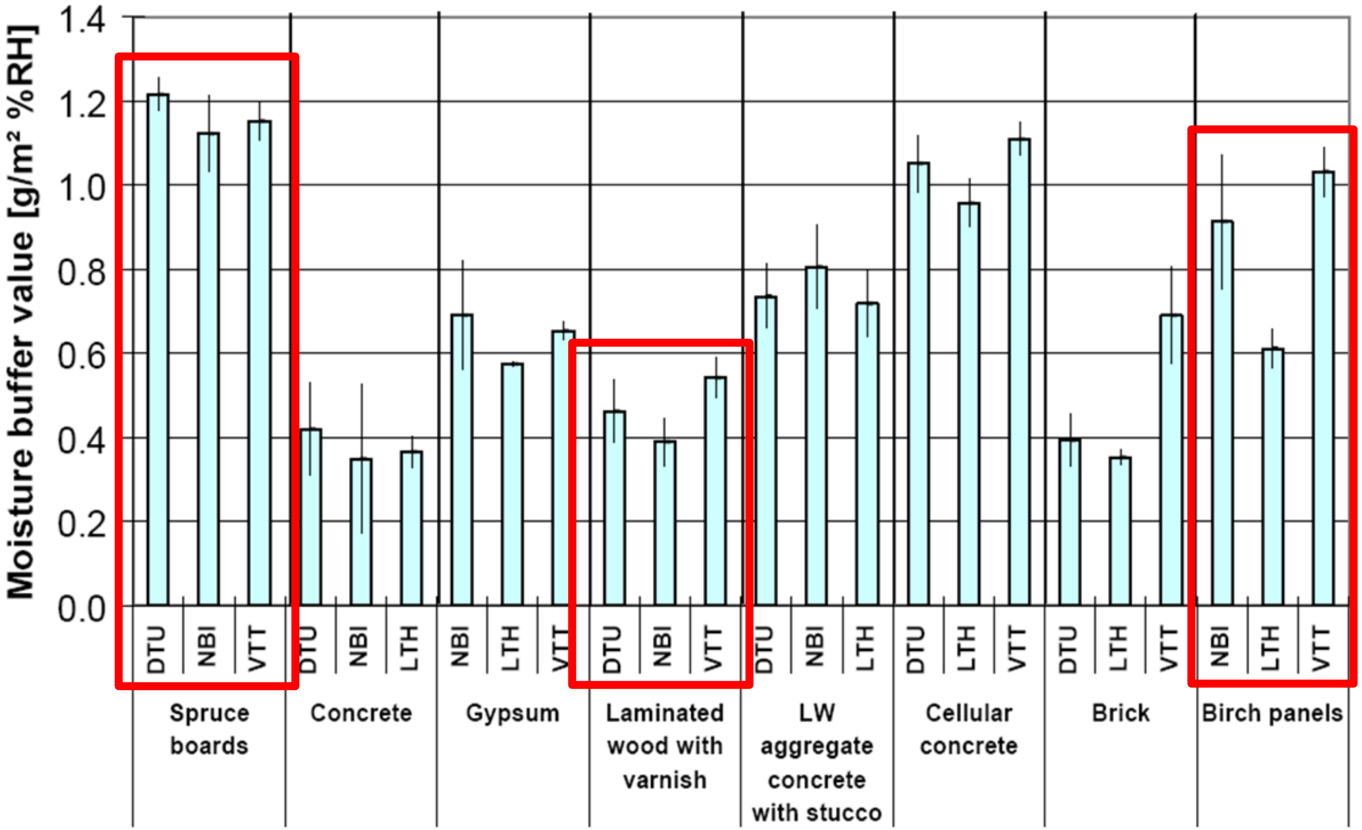


Influence of relative humidity



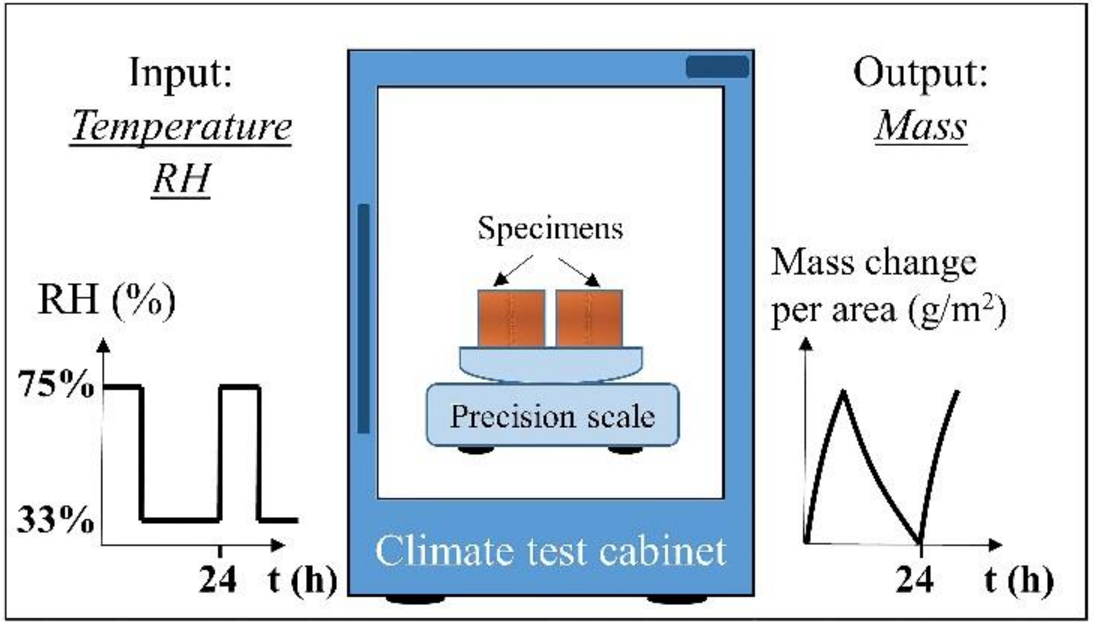
*Insufficient Data Above 50% Relative Humidity

Moisture buffering of building materials



(**Source:** *Moisture Buffering of Building Materials. Report BYG·DTU R-126, 2005. Department of Civil Engineering, Technical University of Denmark. Rode, C., Peuhkuri, R., Mortensen, L.H., Hansen, K.K., Timem B., Gustavsen, A., Ojanen, T., Ahonen, J. Svennberg, K., Harderup, L-E. and Arfvidsson J. Editors)*

Measuring moisture buffering ability



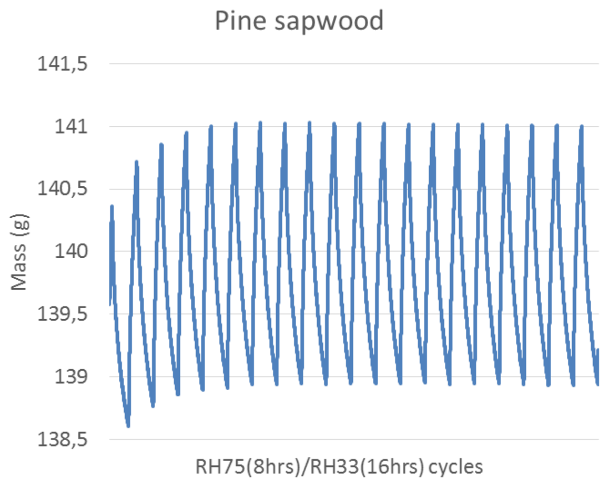
MBVpractical=Δm/S·ΔRH

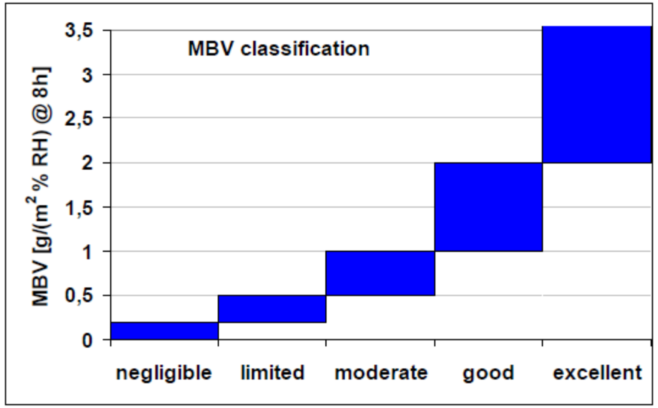
Δm – moisture exchange
S – open surface area
ΔRH – change in relative humidity

Calculations and measurements were done in accordance with NORDTEST method

- How do different species buffer relative humidity?
- Is the buffering ability anisotropic?

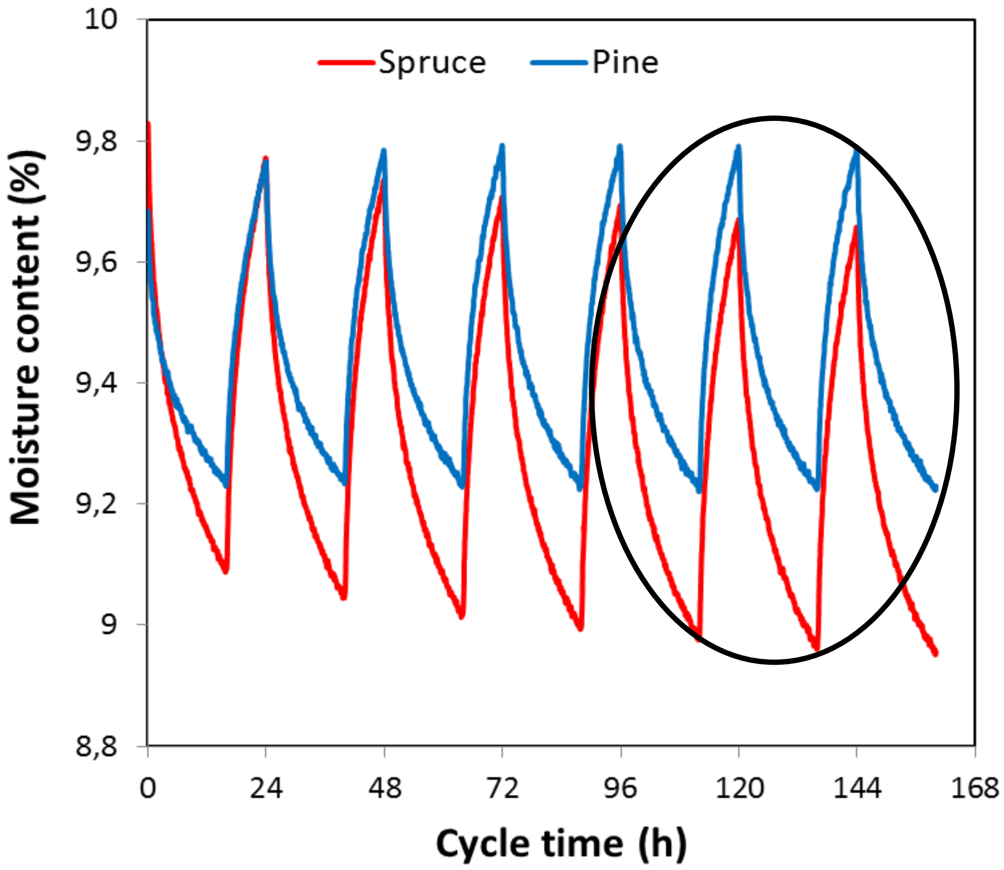
Practical Moisture Buffering Value (MBV)





Practical Moisture Buffer Value classes according to the Nordtest method

Buffering capacity: radial orientation



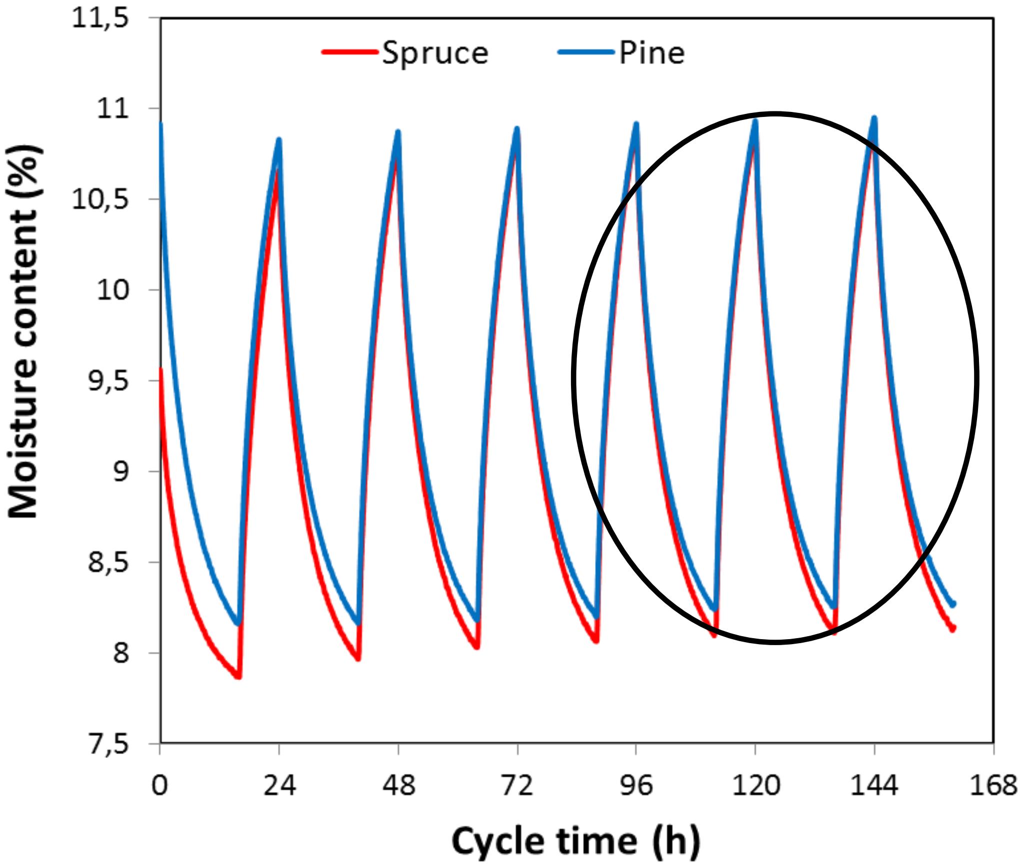
When mass change is less than 5% within cycles and between 3 consecutive cycles -> $MBV_{practical}$

$MBV_{practical}$

Spruce:
1.43 g/(m^2 %rh)

Pine:
1.23 g/(m^2 %rh)

Buffering capacity: axial orientation

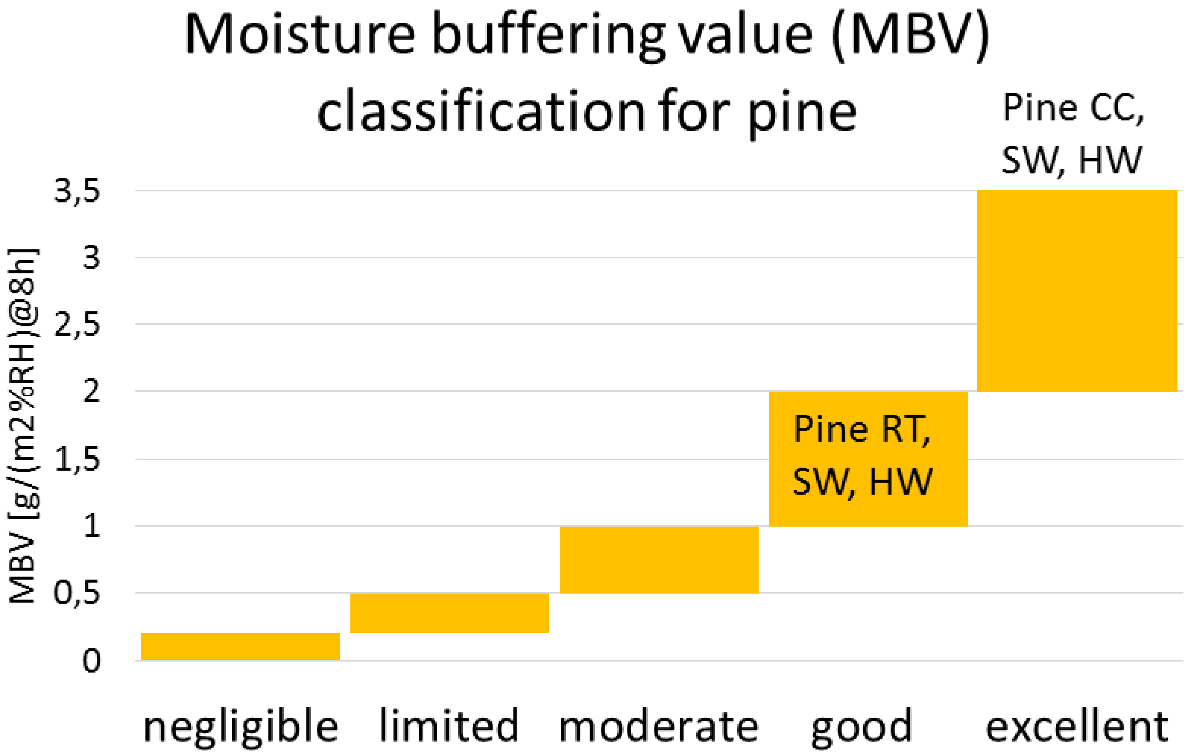


When mass change is less than 5% within cycles and between 3 consecutive cycles -> $MBV_{practical}$

$MBV_{practical}$

Spruce:
5.83 g/(m^2 %rh)

Pine:
5.38 g/(m^2 %rh)



RT is “radial-tangential” orientation; **CC** is “cross-cut” i.e. transverse surface; **SW** is “sapwood”; **HW** is “heartwood”

Moisture buffering summary

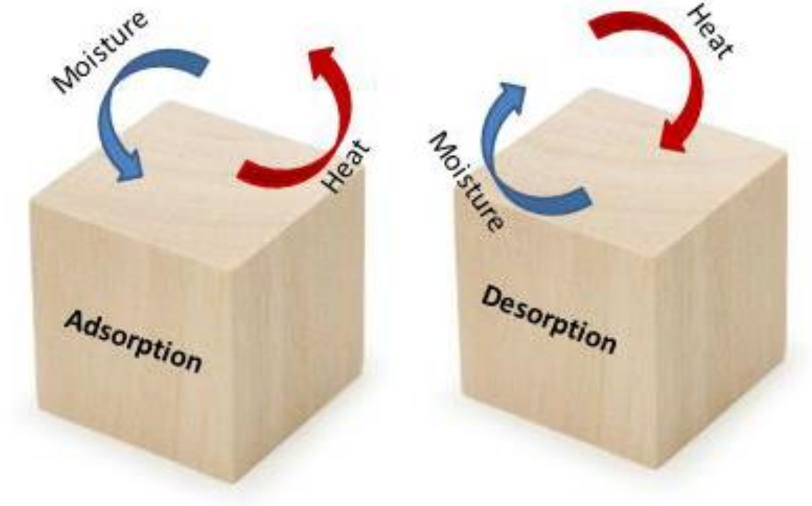
- Buffering found to be about 4 x greater axially than transversely
- Distinct species effects: greater buffering capacity in softwood species
- Heartwood less effective than sapwood (in pine)

Right: *Concept moisture buffering panel created by students of the Aalto University Integrated Interior Wooden Surfaces course*

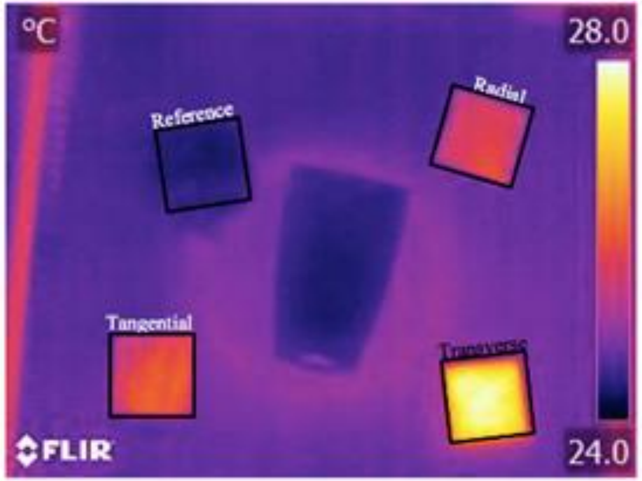
Heat of sorption

Latent heat of sorption

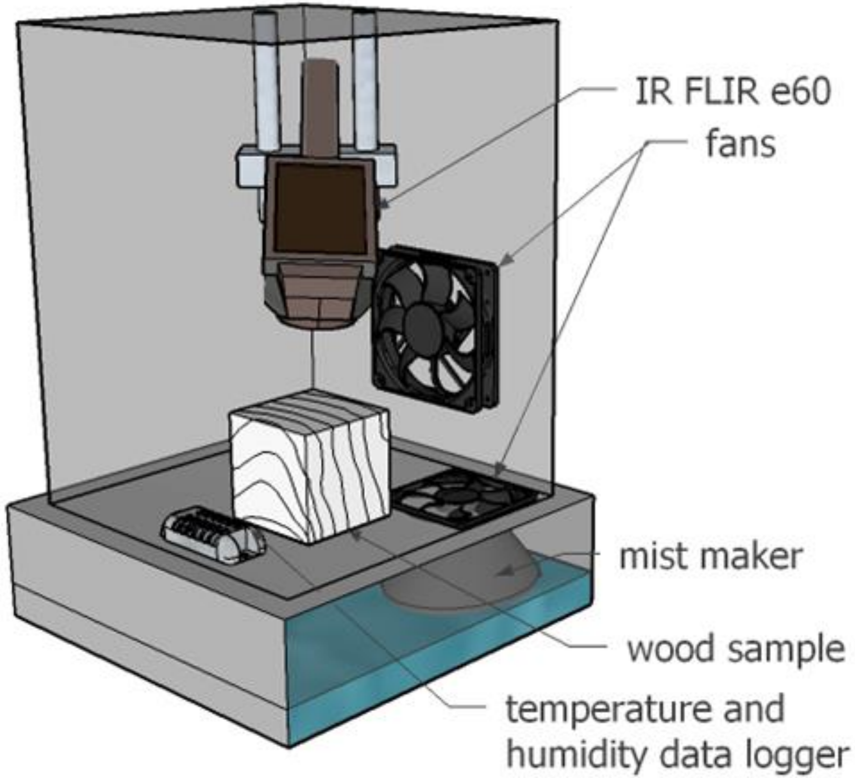
- When wood adsorbs moisture from the surroundings, heat is released
- Conversely when wood is dried heat is required
- This effect can help to thermally buffer the internal climate of a room, leading to the concept of "hygrothermal mass"

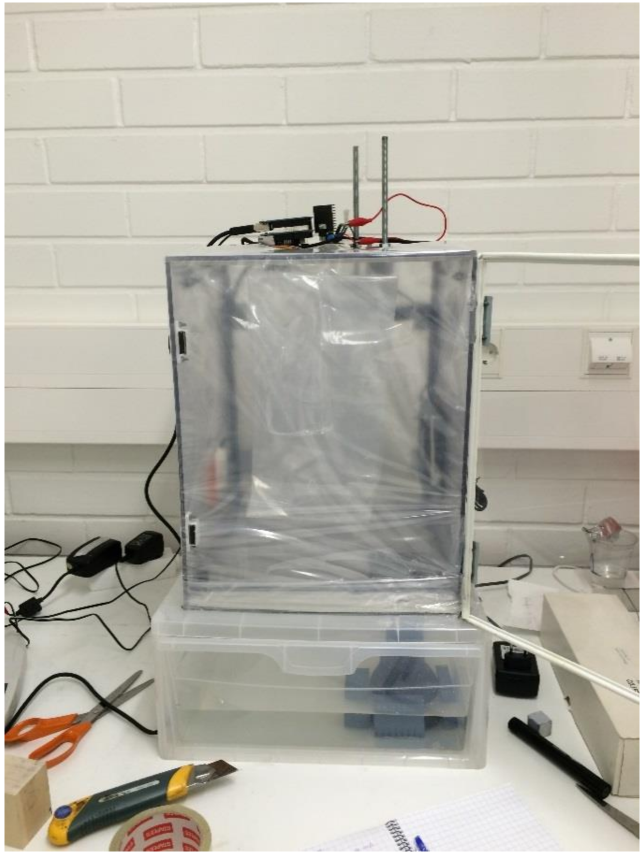


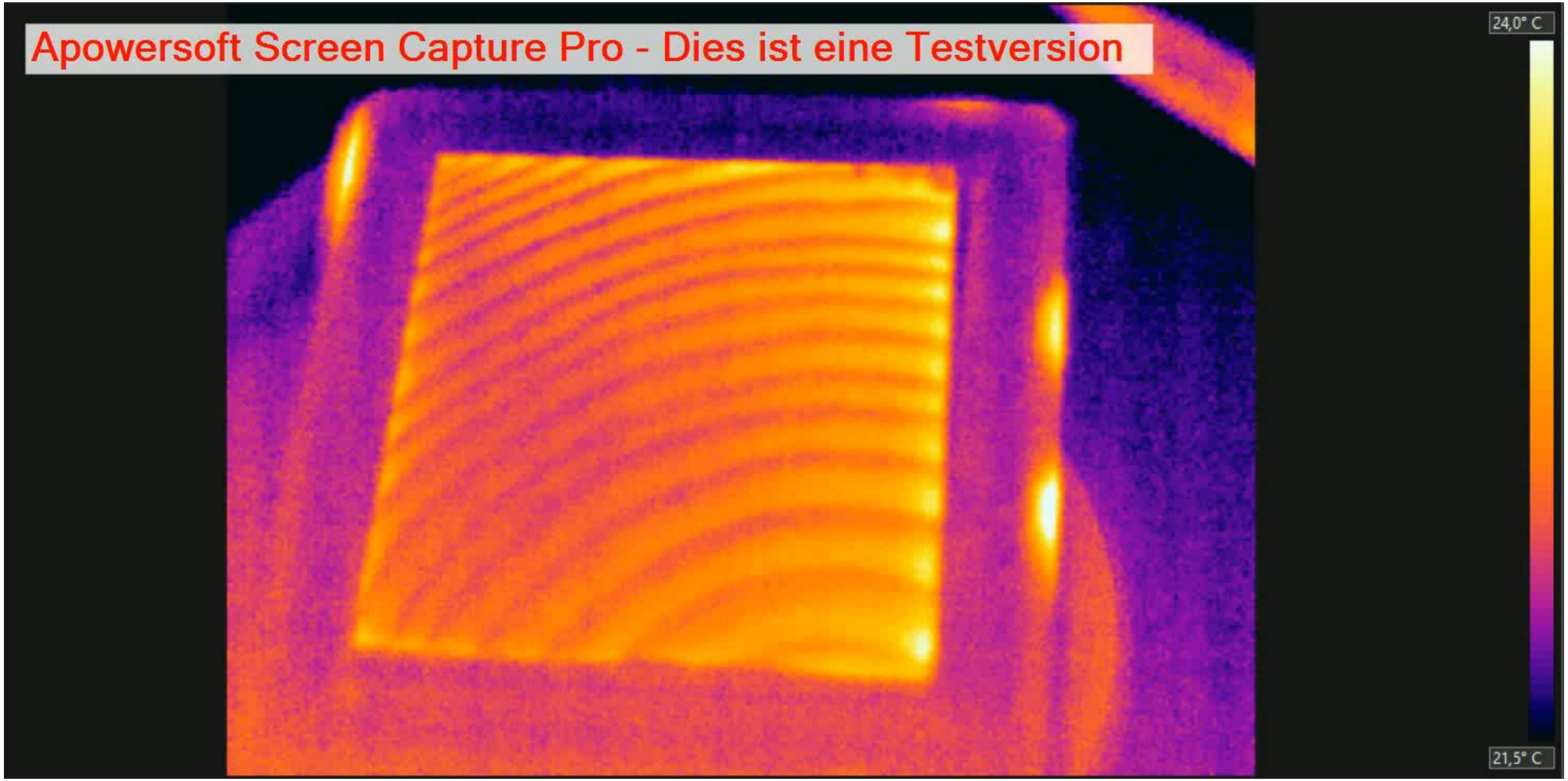
Measuring surface temperature changes in wood due to sorption



Experimental



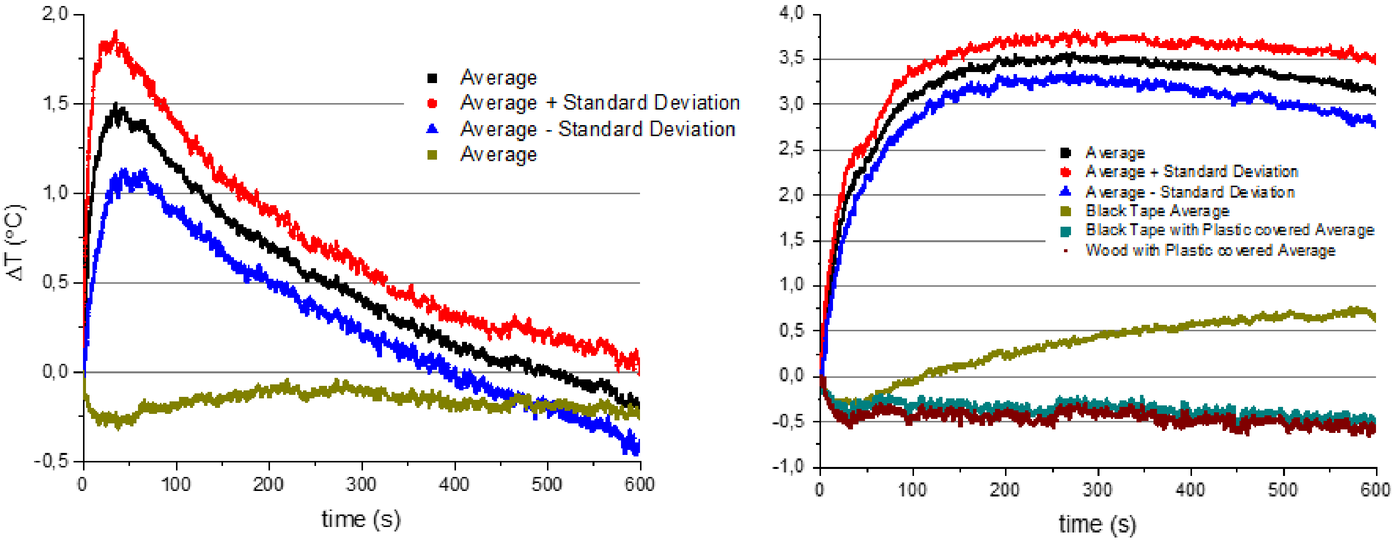




Temperature rise on the transverse surface of a pine wood block during adsorption

Surface temperature rise due to heat of adsorption

Bone dry wood ➞ 90% RH



Tangential surface — Transverse surface

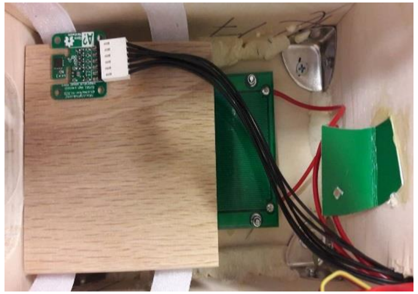
(**Source**: Dupleix, A., Van Nguyen, T., Vahtikari, K. and Hughes, M. (2018). The anisotropic temperature rise on wood surfaces during adsorption measured by thermal imaging. *Wood Science and Technology* **52**(1): 167–180)

People and materials

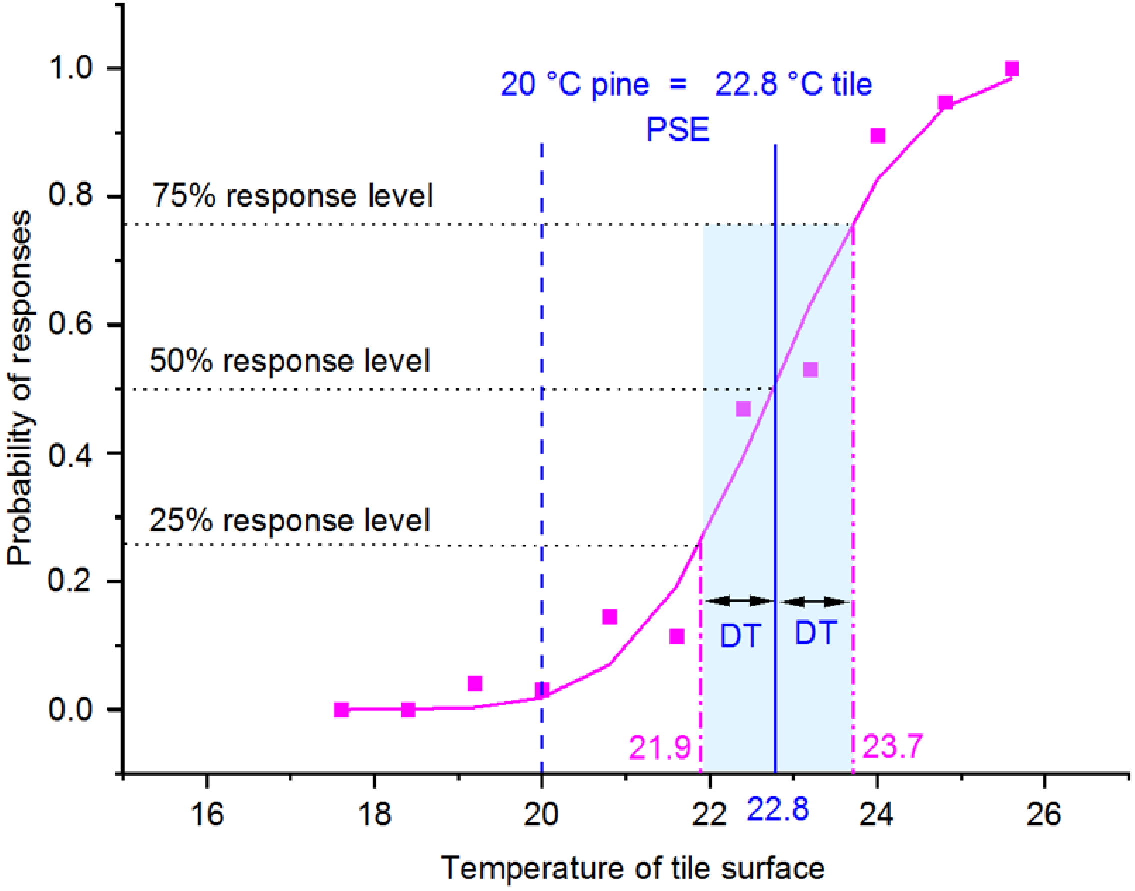
How much warmer is ‘*warmer*’?

Test set-up

.

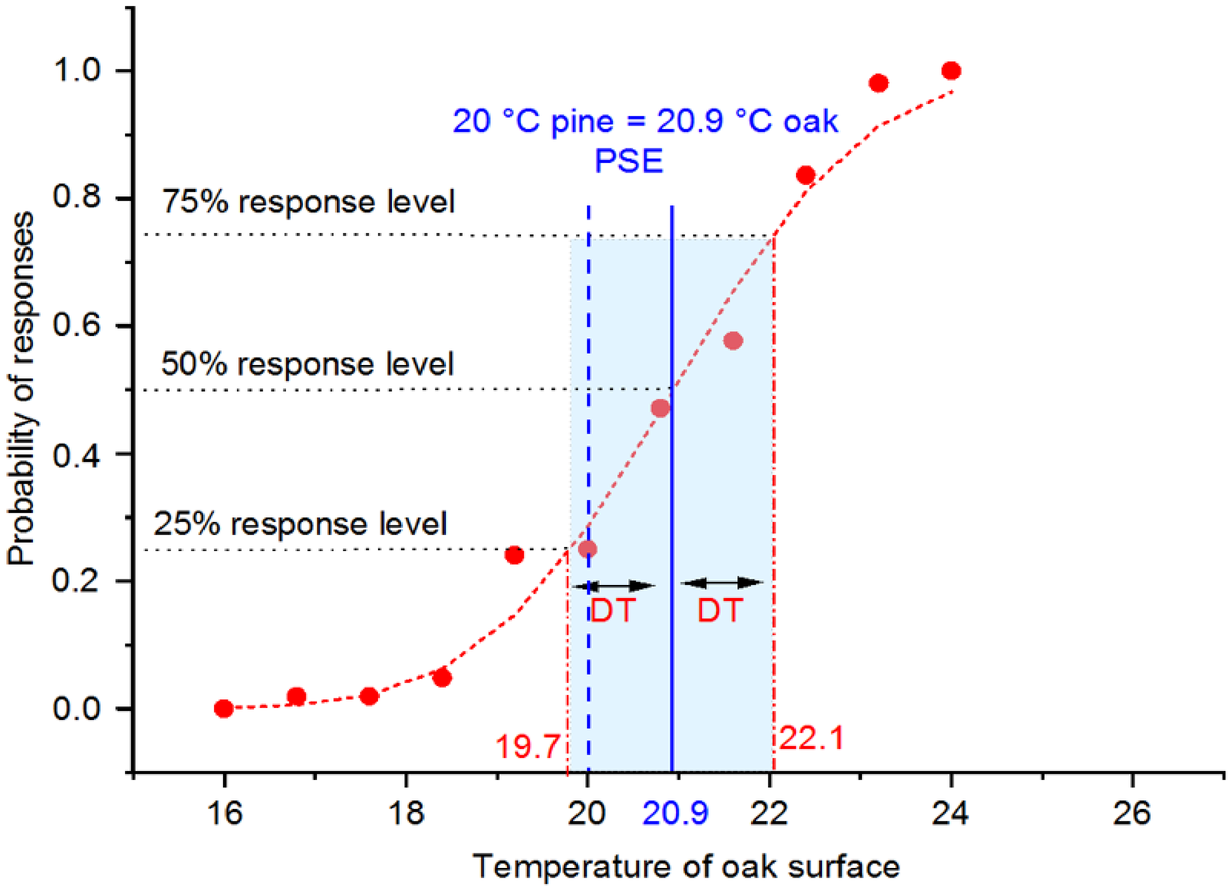


Ceramic tile vs pine



(Source: Bhatta S.R., Tiippana K., Vahtikari K., Kiviluoma P., Hughes M., Kyttäa M. (2019) Quantifying the sensation of temperature: A new method for evaluating the thermal behaviour of building materials. *Energy & Buildings*, 195, 26–32)

Oak vs pine



(**Source**: Bhatta S.R., Tiippana K., Vahtikari K., Kiviluoma P., Hughes M., Kyttäa M. (2019) Quantifying the sensation of temperature: A new method for evaluating the thermal behaviour of building materials. *Energy & Buildings*, 195, 26–32)

Final thoughts:

- Wood is a good insulator, with relatively high thermal mass – good for energy-efficient buildings
- Wood can buffer internal relative humidity, helping to passively maintain a comfortable and healthy indoor environment
- Heat of sorption can influence the energy balance and give rise to the concept of “hygrothemal mass”
- Haptic properties could be used in interior design to create a more thermally comfortable environment.
- Can these lead to reduced heating/cooling energy demands?

Part III: wood & materials-efficiency

nature sustainability

PERSPECTIVE

https://doi.org/10.1038/s41893-019-0462-4

Buildings as a global carbon sink

Galina Churkina[1,2*], Alan Organschi[3,4], Christopher P. O. Reyer[2], Andrew Ruff[3], Kira Vinke[2], Zhu Liu[5], Barbara K. Reck[1], T. E. Graedel[1] and Hans Joachim Schellnhuber[2]

The anticipated growth and urbanization of the global population over the next several decades will create a vast demand for the construction of new housing, commercial buildings and accompanying infrastructure. The production of cement, steel and other building materials associated with this wave of construction will become a major source of greenhouse gas emissions. Might it be possible to transform this potential threat to the global climate system into a powerful means to mitigate climate change? To answer this provocative question, we explore the potential of mid-rise urban buildings designed with engineered timber to provide long-term storage of carbon and to avoid the carbon-intensive production of mineral-based construction materials.

(**Source**: Churkina, G., Organschi, A., Reyer, C.P.O. et al. Buildings as a global carbon sink. *Nat Sustain* **3,** 269–276 (2020). https://doi.org/10.1038/s41893-019-0462-4)

Buildings: a source of future timber?

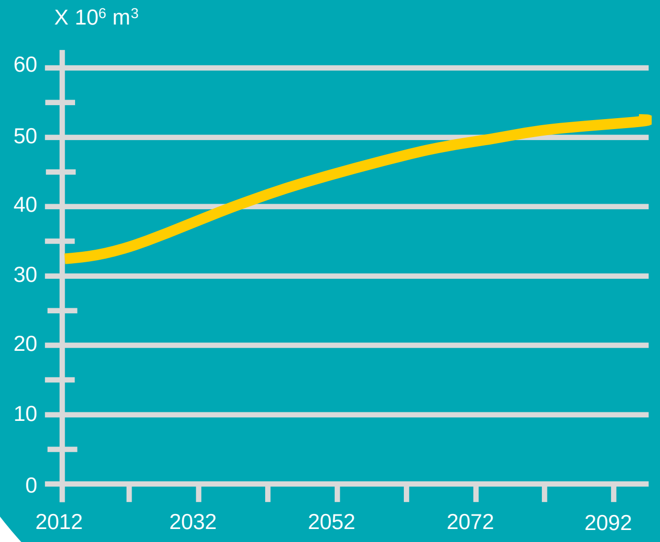
Global production of sawnwood and wood-based panels was approx. **845 million cubic metres** in 2019[1]

[1]*FAOSTAT-Forestry database*

Aalto University

How much wood is available?

Timber in building stock



(Source: Kalcher et al. 2017)

- A recent study[1] showed that there is a stock of approximately 32 Mm^3 wood in residential buildings in Austria, increasing to over 50 Mm^3 by 2100
- Another study[2] found that there is around 32 Mm^3 of wood in Finnish residential buildings

[1]*Kalcher et al. (2017): Resources, Conservation and Recycling 123 143–152*

[2]*Nasiri, B., Piccardo, C. and Hughes, M. (2021): Estimating the timber stock in residential houses in Finland. Waste Management, 135, 318-326*

8.6%

The world currently recycles 8.6% of materials

World's consumption of materials hits record 100bn tonnes a year

Unsustainable use of resources is wrecking the planet but recycling is falling, report finds

▲ Half of the 100.6bn tonnes of materials were sand, clay, gravel and cement for building, plus minerals quarried for fertiliser. Photograph: Zoonar GmbH/Alamy

The Guardian (22.1.2020)

DIRECTIVES

The Vision: By 2050 the EU's economy has grown in a way that respects resource constraints and planetary boundaries, thus contributing to global economic transformation. Our economy is competitive, inclusive and provides a high standard of living with much lower environmental impacts. All resources are sustainably managed, from raw materials to energy, water, air, land and soil. Climate change milestones have been reached, while biodiversity and the ecosystem services it underpins have been protected, valued and substantially restored.

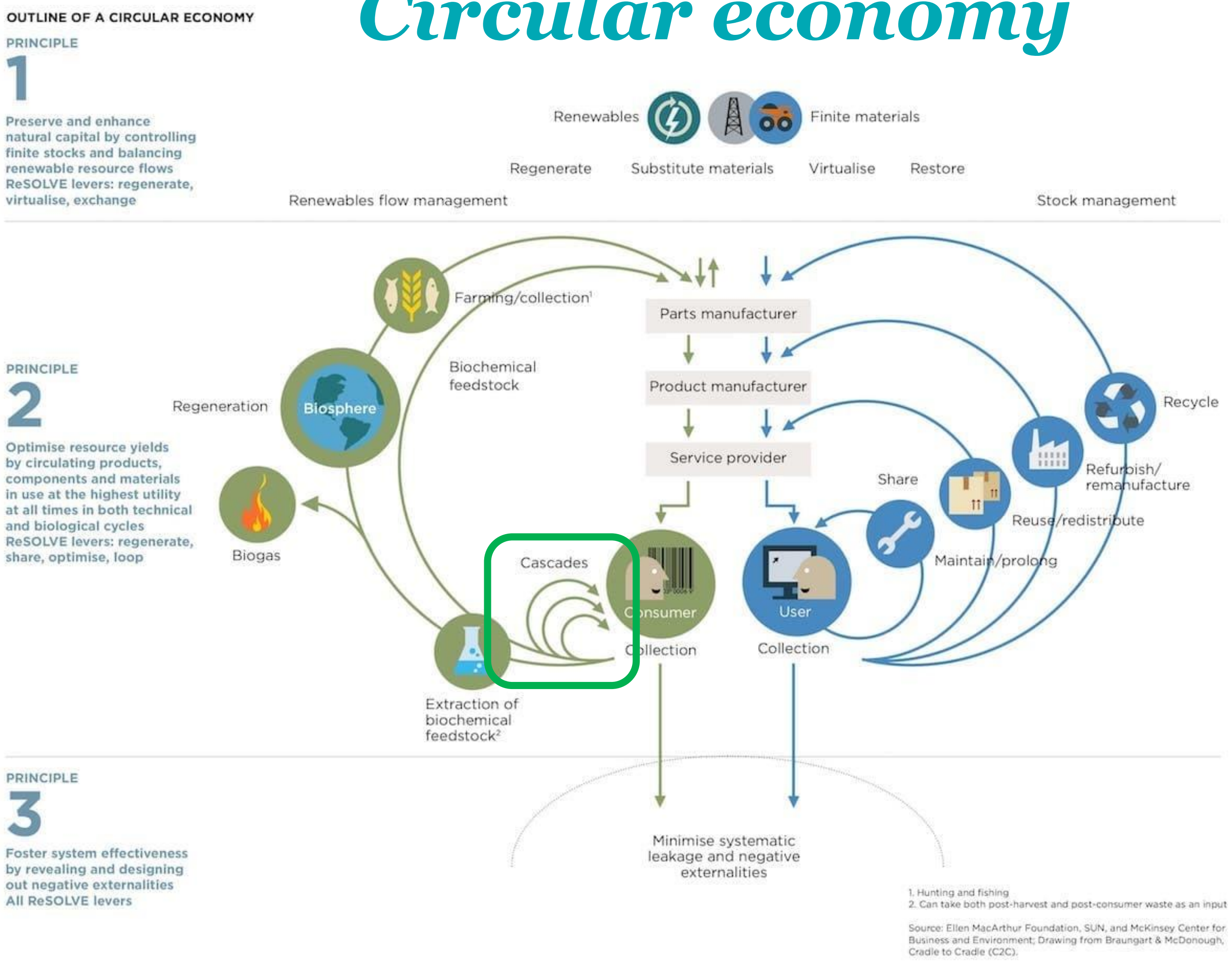
The circular economy

Circular economy ↑ Increasing circularity — Linear economy

	Strategies	
Smarter product use and manu-facture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consu-ming fewer natural resources and materials
Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of mate-rials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

The 9R Framework on the Circular Economy (CE).

Circular economy



https://www.ellenmacarthurfoundation.org/circular-economy/concept/infographic

Improving sustainability by increasing the total amount of wood used in construction

Various mechanisms and incentives required to increase the proportion of wood used in construction and the Bioeconomy

Improving sustainability by increasing the total amount of wood used in construction

Various mechanisms and incentives required to increase the proportion of wood used in construction and the Bioeconomy

What impact does this have on the sustainability of wood use?

Improving sustainability by increasing the total amount of wood used in construction

Various mechanisms and incentives required to increase the proportion of wood used in construction and the Bioeconomy

What impact does this have on the sustainability of wood use?

Possible negative consequences if we increase wood use too much[1]

Aalto University

[1] *Jonsson, R., Rinaldi, F., Pilli, R. Fiorese, G., Hurmekoski, E., Cazzaniga, N., Robert, N. and Camia, A. (2021). Boosting the EU forest-based bioeconomy: Market, climate, and employment impacts. Technological Forecasting & Social Change 163 (2021) 120478*

Improving sustainability by increasing the total amount of wood used in construction

Various mechanisms and incentives required to increase the proportion of wood used in construction and the Bioeconomy

Probable supply shortages if we wish to maintain and develop the role of forests in the provision of ecosystem services

Aalto University

How do we maximize the **substitution** and carbon **storage** benefits of wood products in construction, without compromising the **sequestration** and **sink** potential of forests as well as other **eco-system** services?

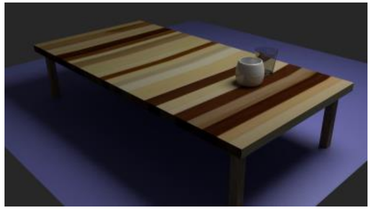
Aalto Sustainability Hub

Materials efficiency
&
Resource cascading

Materials efficiency

1. **Efficient** utilisation of raw material in production (‘biorefinery’)
2. **Efficiency** in use (extend time in use)
3. **Efficiency** after use (**cascade use**)

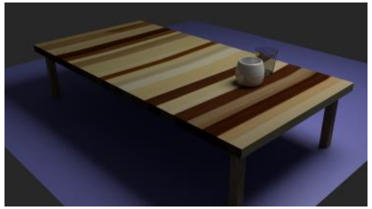
(Source: http://www.eplet.net/Urnes.html)



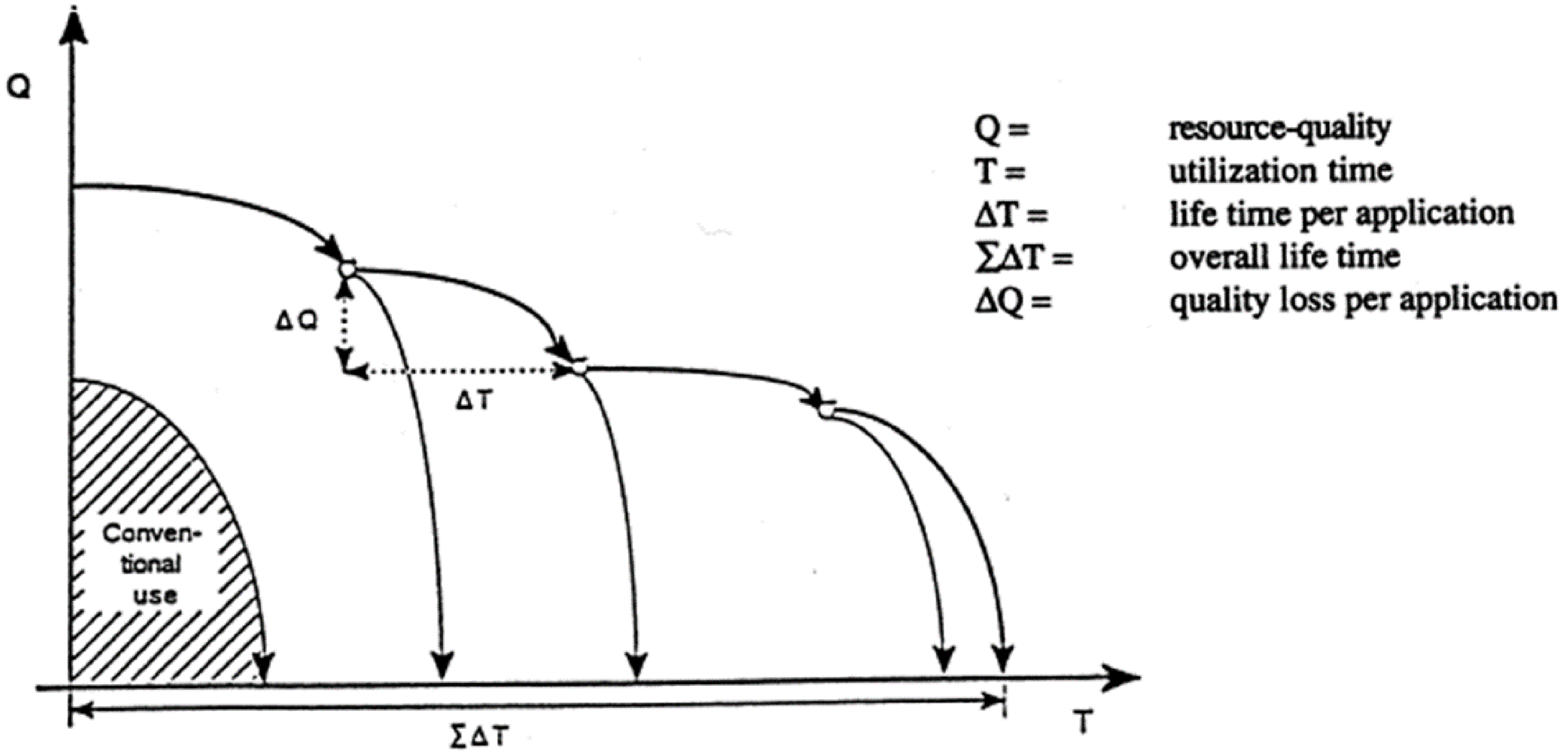
Materials efficiency

1. **Efficient** utilisation of raw material in production ('biorefinery')
2. **Efficiency** in use (extend time in use)
3. **Efficiency** after use (**cascade use**)

(Source: http://www.eplet.net/Urnes.html)



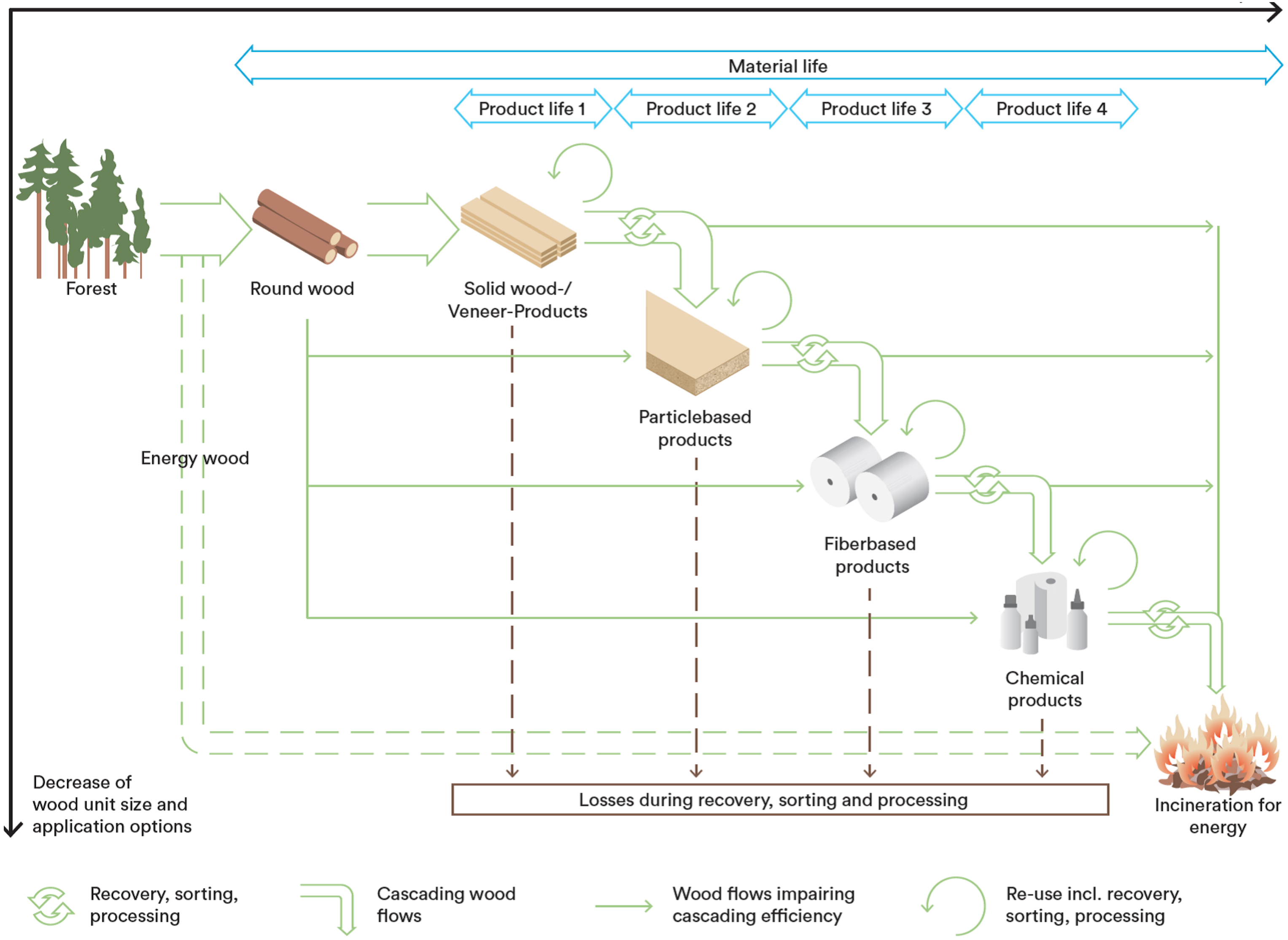
Resource cascading



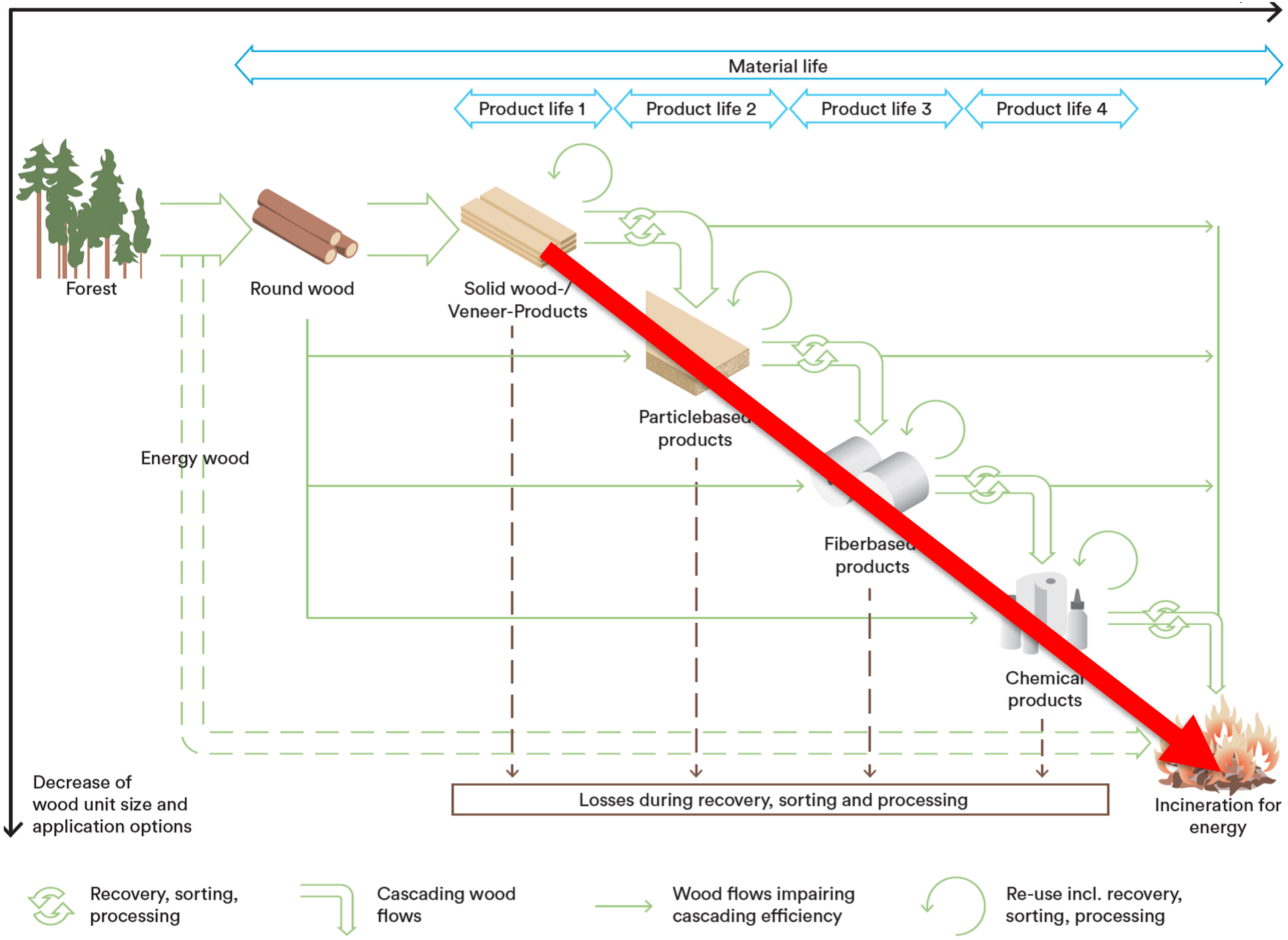
Aalto University

*(**Source**: Fraanje, P.J., Lafleur, M.C.C., 1994. Verantwoord gebruik van hout in Nederland. (Sustainable use of wood in the Netherlands) IVAM Environmental Research, nr. 94/08. University of Amsterdam.)*

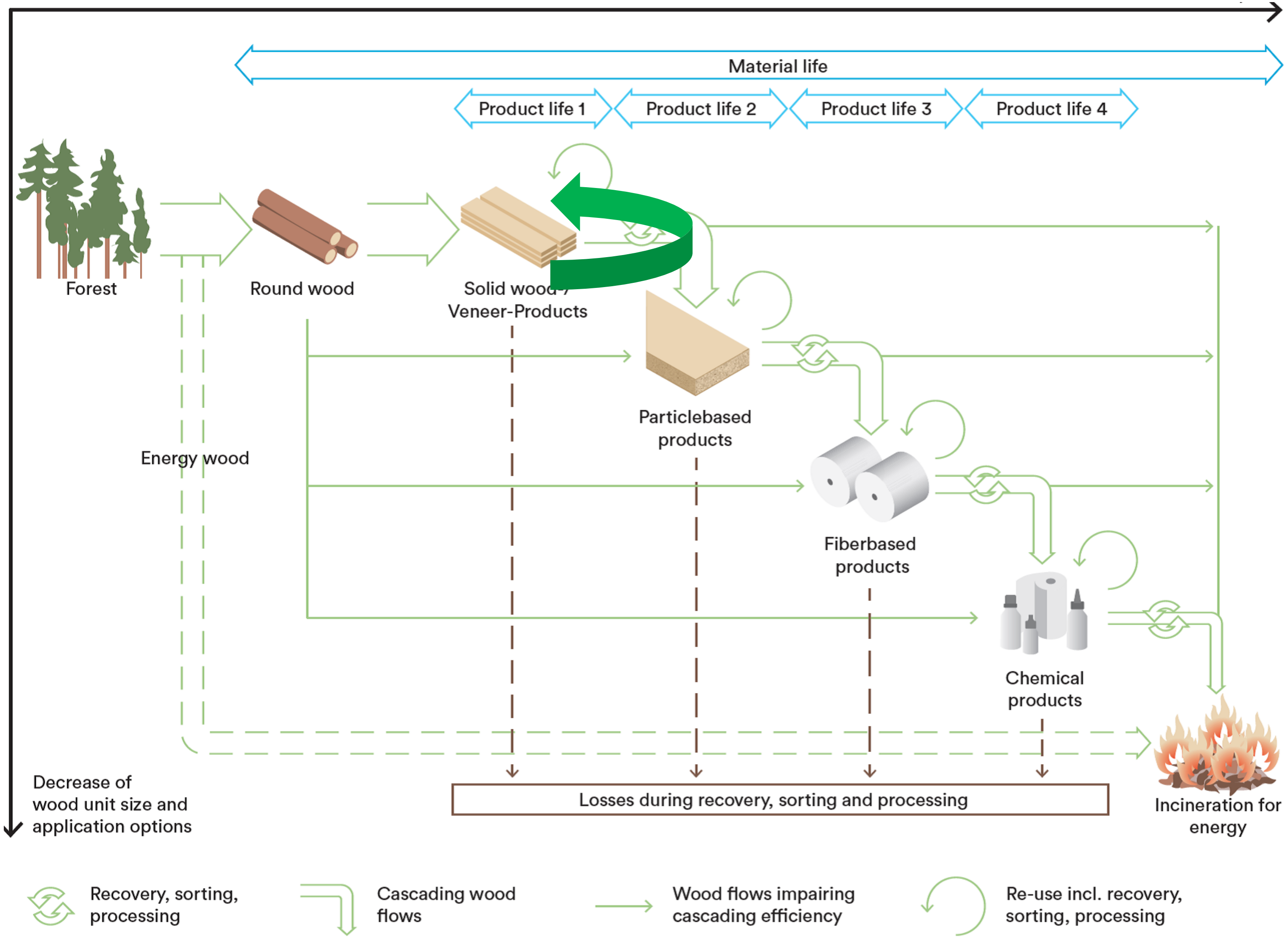
Aalto Sustainability Hub



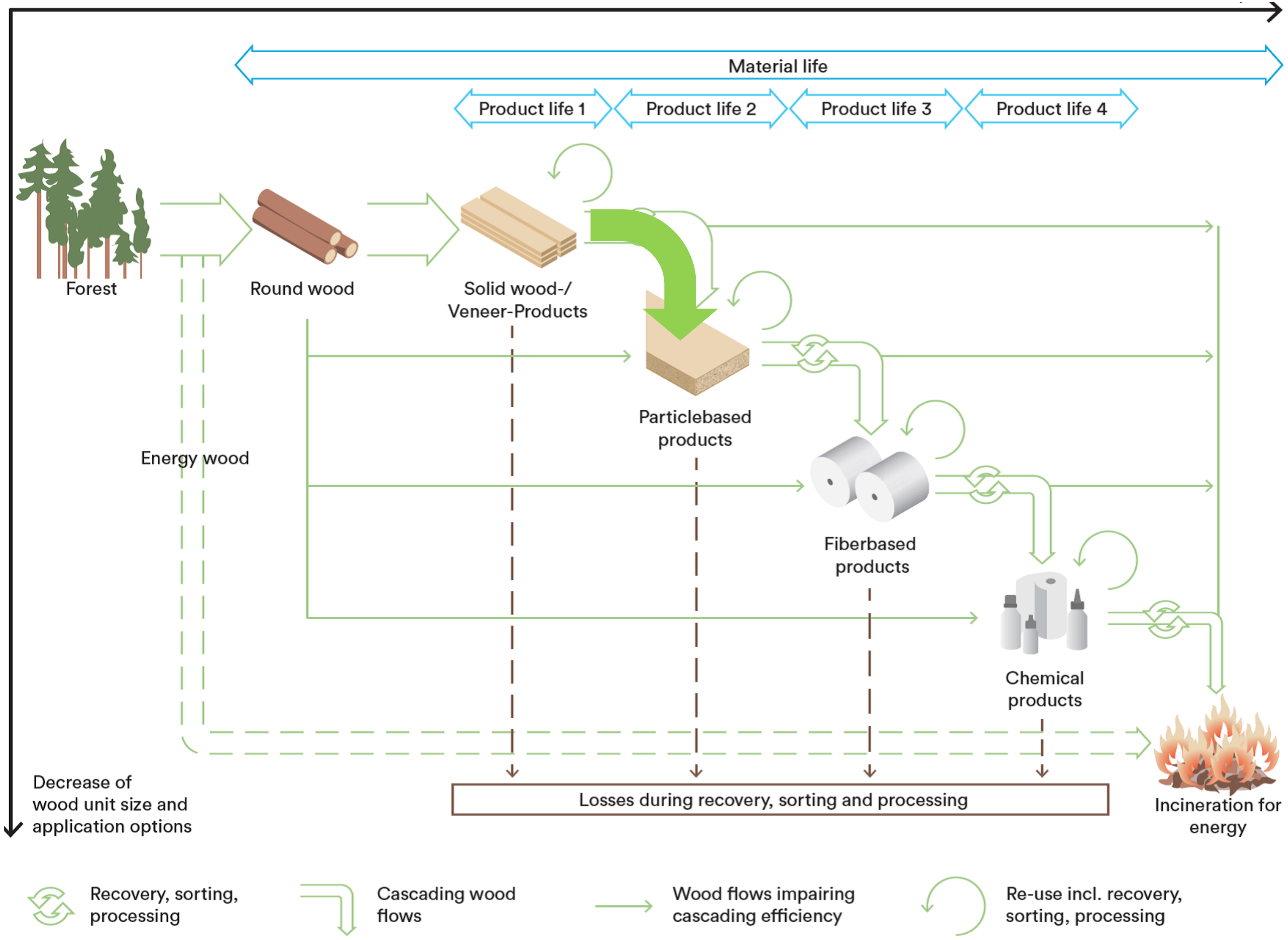
*(**Adapted from:** Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91)*



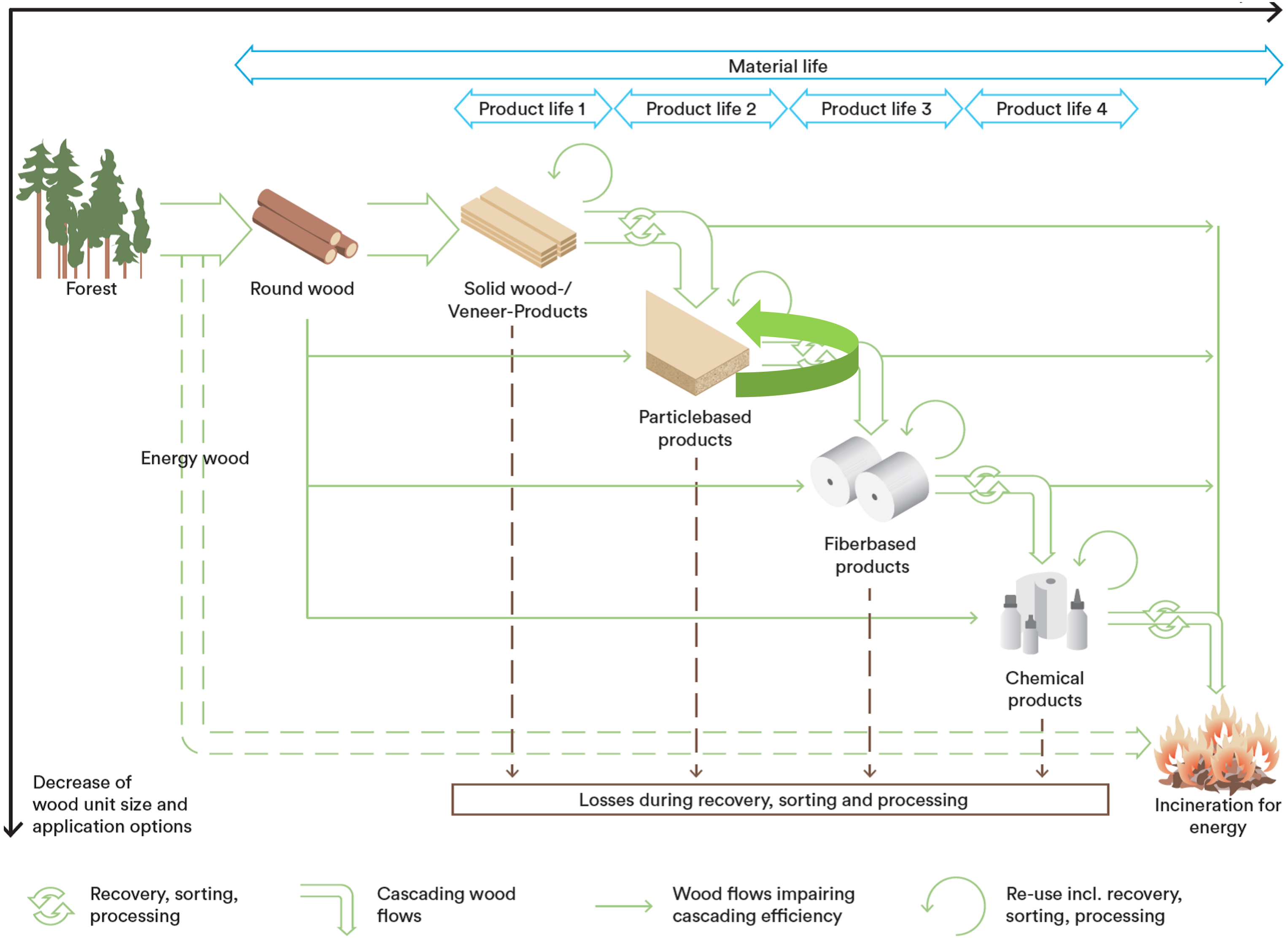
*(**Adapted from:** Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91)*



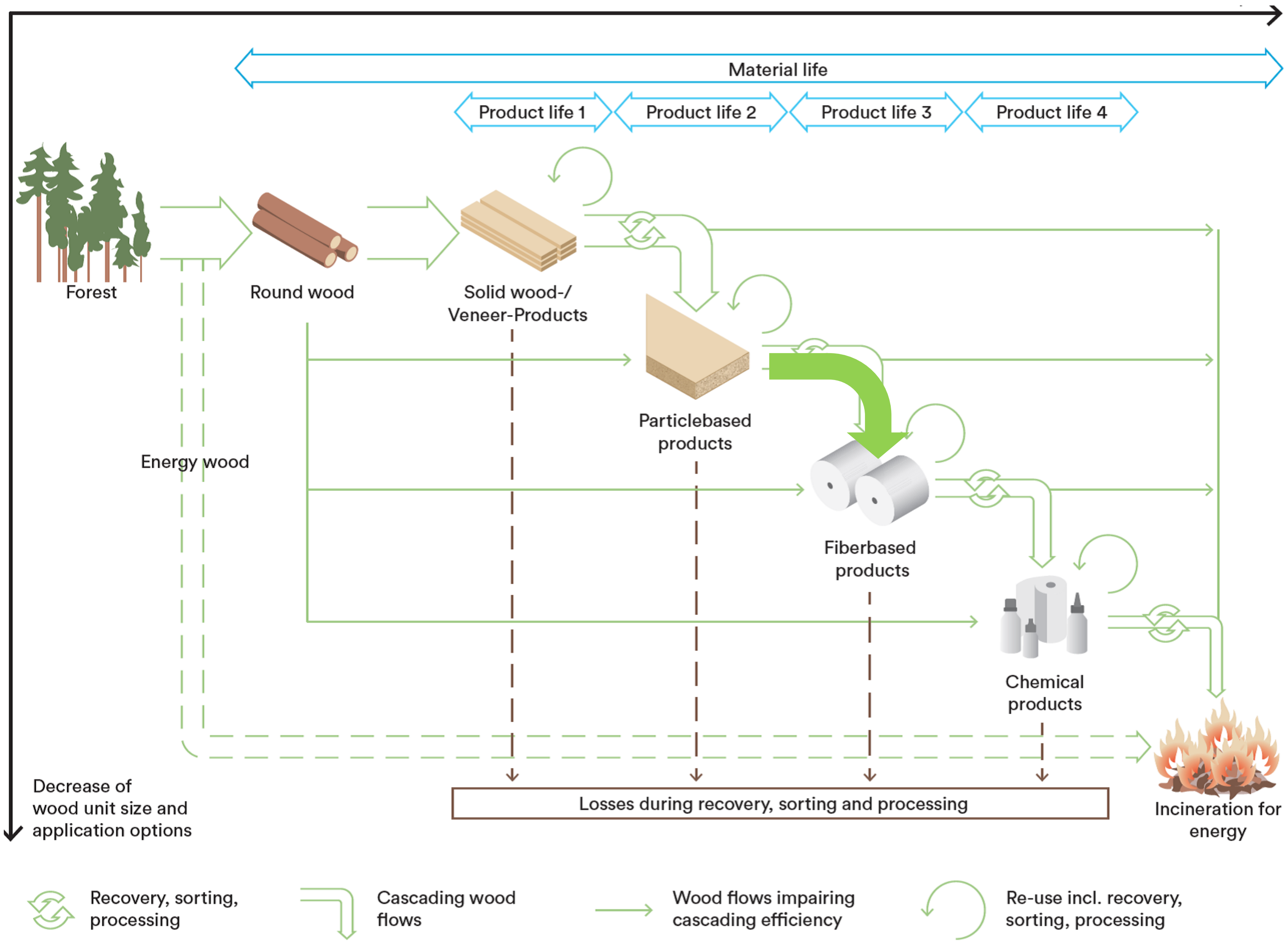
*(**Adapted from:** Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91)*



*(**Adapted from:** Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91)*



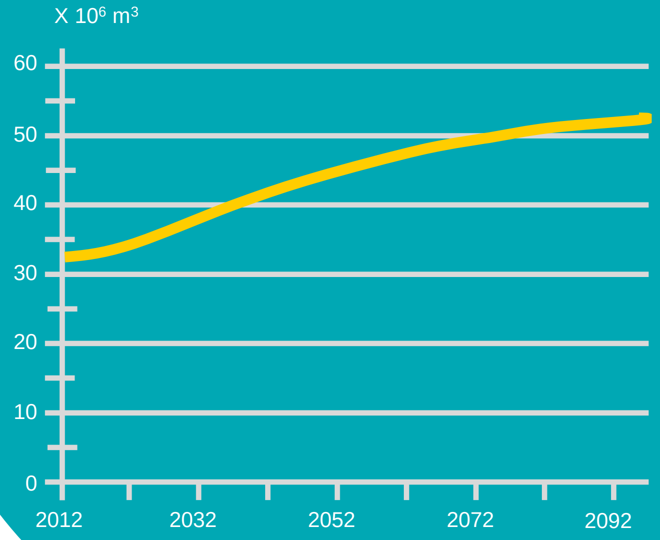
*(**Adapted from:** Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91)*



(***Adapted from:*** *Höglmeier, K. Weber-Blaschke, G. and Richter K. (2013), Resources, Conservation and Recycling 78 81– 91*)

How much wood is available for cascading?

Aalto University



(Source: Kalcher et al. 2017)

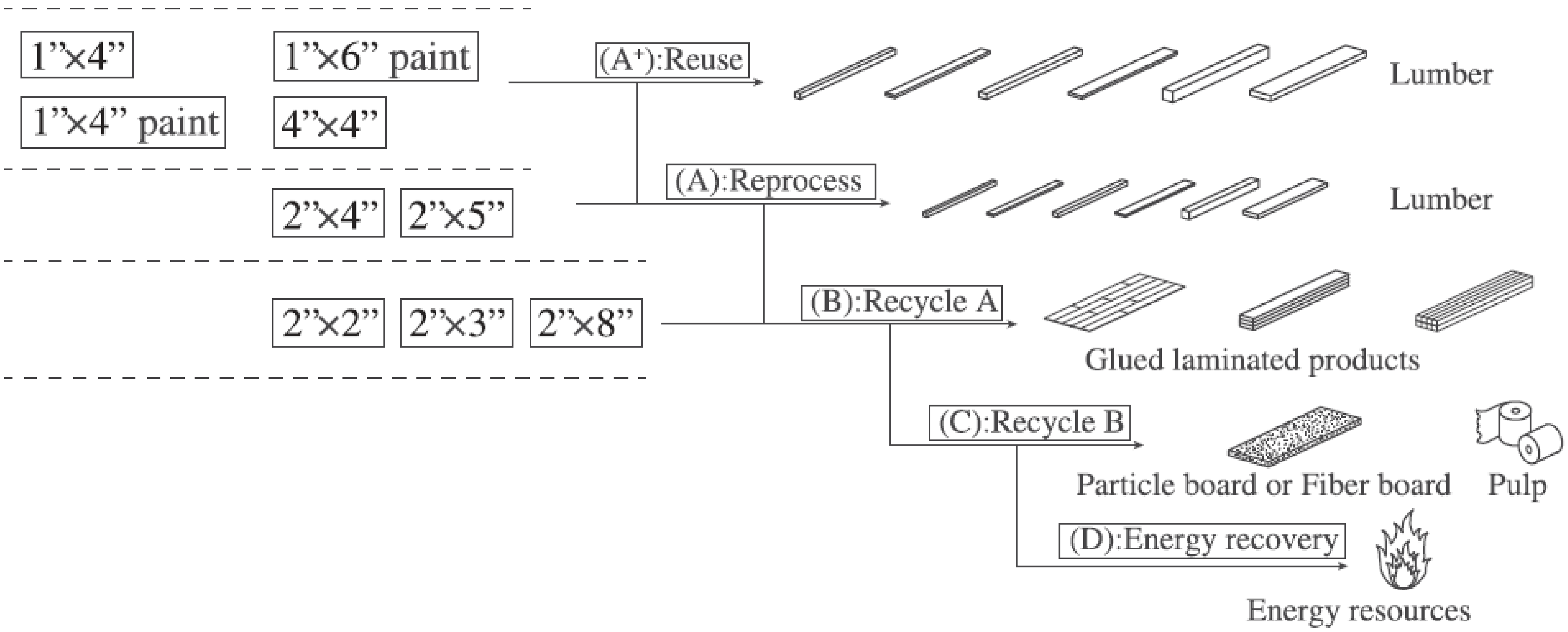
- A recent study[1] showed that there is a stock of approximately 32 Mm^3 wood in residential buildings in Austria, increasing to over 50 Mm^3 by 2100
- Another study[2] found that there is around 17.5 M tons of wood in Finnish residential buildings

[1]*Kalcher et al. (2017): Resources, Conservation and Recycling 123 143–152*

[2]*Nasiri, B., Piccardo, C. and Hughes, M.: Estimating the timber stock in residential houses in Finland. (in preparation)*

Aalto Sustainability Hub

Possible cascading flow for demolition wood



(**Source**: Sakaguchi, D., Takano, A. & Hughes, M. (2017): The potential for cascading wood from demolished buildings: potential flows and possible applications through a case study in Finland, *International Wood Products Journal*, **8**(4): 208-215.)

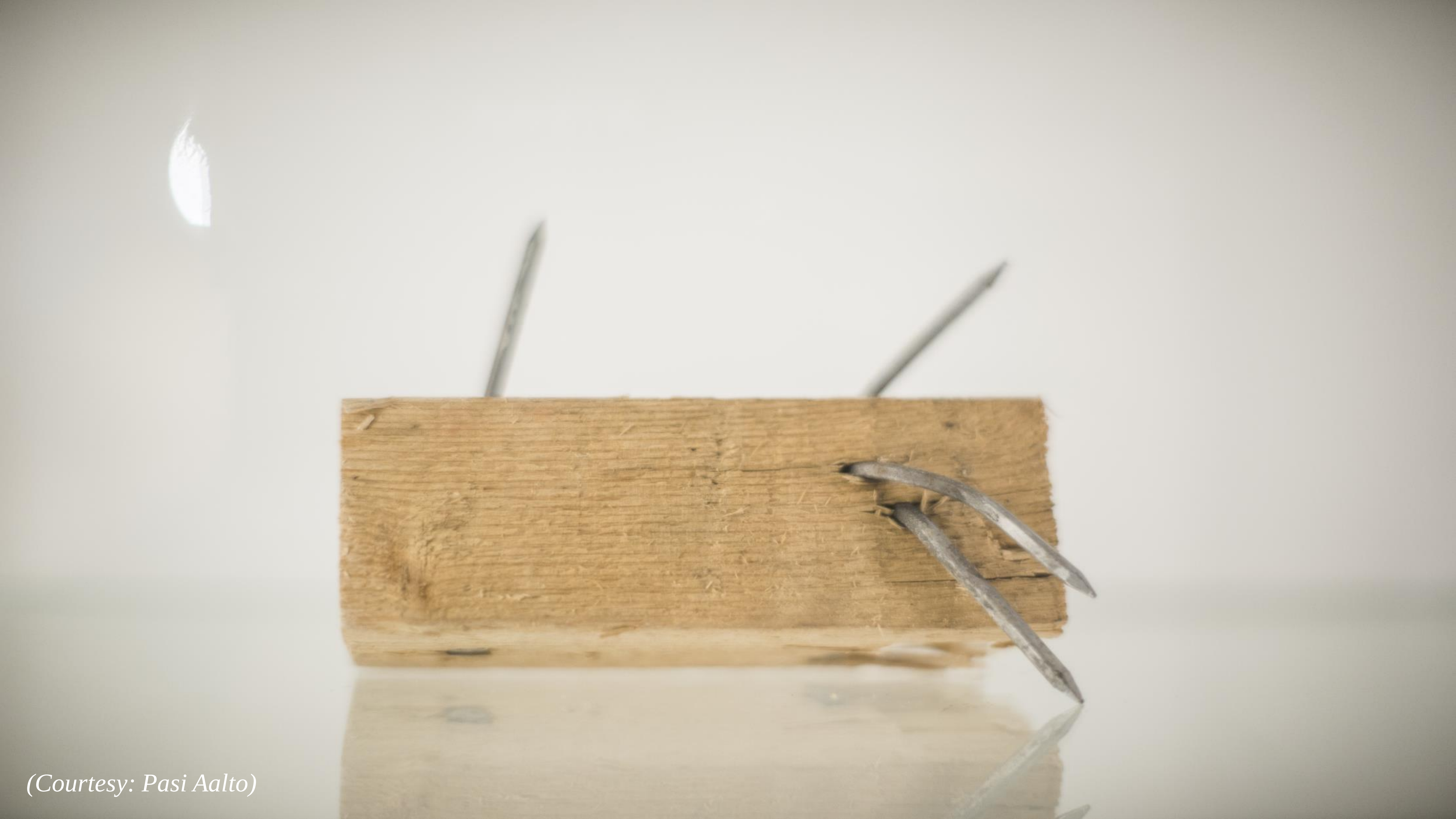
These studies tell us how much wood is in the built environment, but nothing about the types of product, their dimensions or quality ……..

Wood recovered from a demolition in Porvoo, Finland

(**Source**: Sakaguchi, D., Takano, A. & Hughes, M. (2017): The potential for cascading wood from demolished buildings: potential flows and possible applications through a case study in Finland, *International Wood Products Journal*, **8**(4): 208-215.)

So what is the problem?

(Courtesy: Chiara Piccardo)



(Courtesy: Pasi Aalto)

(Courtesy: Pasi Aalto)

“Upcycling”?

http://www.colourbox.com

https://www.quanex.com

Adding value

Design for disassembly


(Courtesy: Daishi Sakaguchi)

- Current **demolition** practices not compatible with material recovery
- This limits **cascading** options
- Buildings should be designed with **disassembly** and recovery of materials in mind
- Exploring this is the basis of the InFutUReWood project

InFutUReWood

Final thoughts:

- Future building will use up a considerable proportion of the remaining carbon budget
- Wood can have a positive impact in terms of sustainability, especially climate change mitigation
- Extend the lifetimes of buildings
- This impact can be enhanced through reuse and recycling
- Reuse and recycling can be supported through design for disassembly to enable recovery of high-quality materials for cascading
- We should think of buildings as stores of valuable materials