Electronic Supplementary Material (ESI) for

Passive climate regulation with transpiring wood for buildings with increased energy efficiency

Yong Ding [a,b], *Christopher H. Dreimol* [a,b], *Robert Zboray* [c], *Kunkun Tu* [a,b], *Tobias Keplinger* [a,b], *Guido Panzarasa* [a,b], *Ingo Burgert* * [a,b]

[a] Wood Materials Science, Institute for Building Materials, ETH Zürich, 8093 Zürich, Switzerland

[b] WoodTec Group, Cellulose & Wood Materials, Empa, 8600 Dübendorf, Switzerland

[c] Center for X-ray Analytics, Empa, 8600 Dübendorf, Switzerland

* Corresponding author: iburgert@ethz.ch

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Supplementary Text

Calculation of energy-saving ratio

The indirect energy saving derived from the use of transpiring wood in buildings is calculated based on the reduction of the temperature fluctuations. A house model with four sample-allocating apertures, or “windows”, was fabricated to enable the measurements. Ideal living conditions are assumed for the test, that is: 23^{o}C, R.H. 40-60%. Deviations from the ideal conditions are generated due to diurnal and seasonal climate changes. When the indoor climate is shifting away from these ideal conditions, energy needs to be consumed to bring the indoor temperature back by heating or cooling. Large temperature fluctuations lead to more energy consumption in maintaining the indoor temperature. We defined the difference between the practical indoor temperature and ideal indoor temperature as the workload of the indoor climatization system and the workload relates to the energy consumption level of buildings.

When the indoor temperature is lower than the ideal temperature (for example, during nighttime), energy is consumed to heat up indoor space (Fig. S13). The original working load for heating when having with reference wall (PMMA panels, not interacting with moisture) is denoted as A1. By substituting the reference walls with transpiring wooden walls, the transpiring wood would interact with the moisture and passively regulate the indoor temperature. The reduced indoor temperature fluctuation is contributed by the hygrothermal effect of transpiring wood. Since transpiring wood cannot counterbalance entirely the temperature fluctuation, extra energy needs to be consumed to heat the indoor space up to ideal indoor temperature. The working load for heating with transpiring wood walls is denoted as A2. Therefore, the reduced work load for heating contributed by transpiring wood is defined as A3, and

A3 = A1-A2

We defined the energy-saving ratio ($E_{heating}$) for heating with transpiring wood as:

$E_{heating}$ = A3/A1

Likewise, when then indoor temperature is higher than the ideal temperature, energy is consumed to cool down indoor space. The original work load for cooling when having reference walls is defined as A4. The work load for cooling with transpiring wood walls is defined as A5. The reduced work load for cooling by using transpiring wood walls is A6.

A6= A4-A5.

We defined the energy saving efficiency ($E_{cooling}$) for cooling with transpiring wood as:

$E_{cooling}$ = A6/A4

Different geographic locations or climate types required different energy consumption level. In this work, we tested five different conditions (for details please refer to the manuscript).

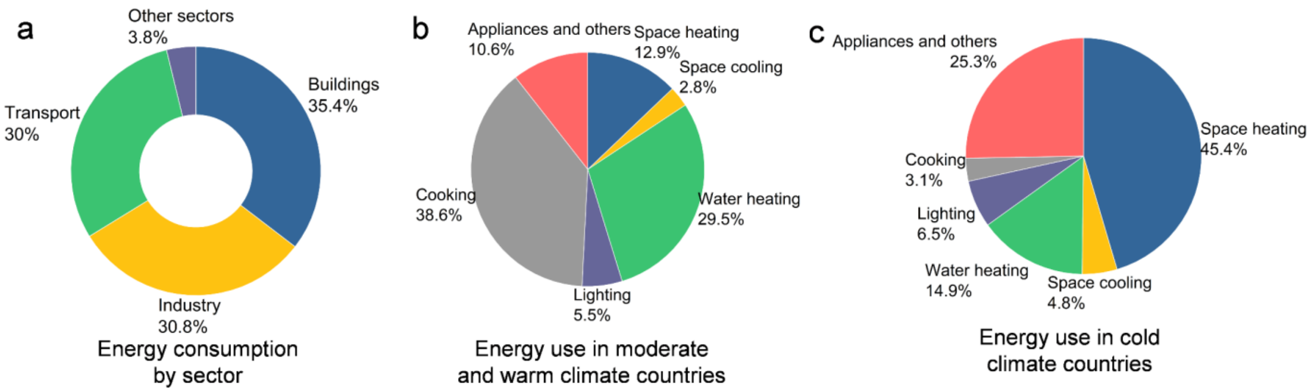

Fig. S1 Overview of global energy consumption. (a) Overall energy consumption of the building sector. (b) Energy consumption in buildings for heating and cooling in moderate climates. (c) Energy consumption in buildings for heating and cooling in cold climates. Data source: Global status report for buildings and construction, IEA. 2021.

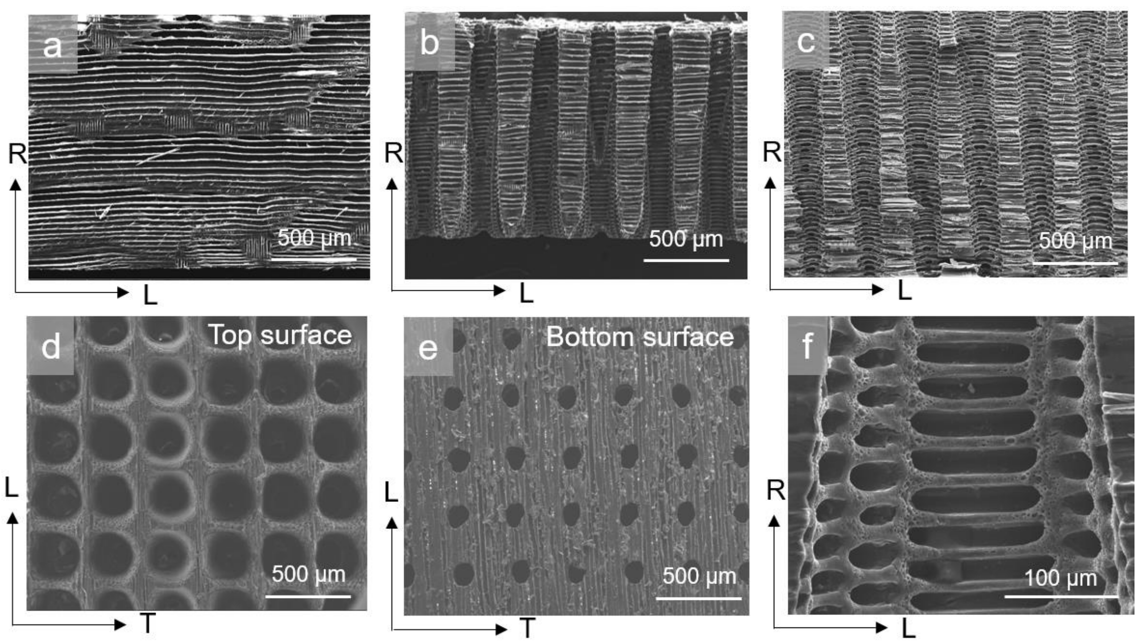

Fig. S2 SEM image showing the morphology of (a) RL plane of native wood samples, (b-f) lasered wood.

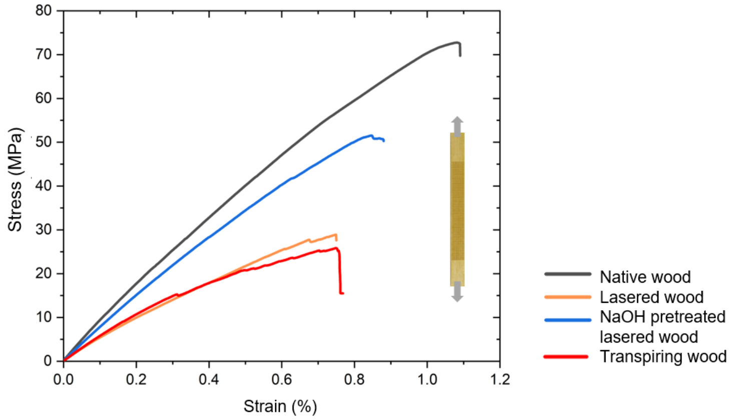

Fig. S3 Strain-stress diagrams from tensile tests.

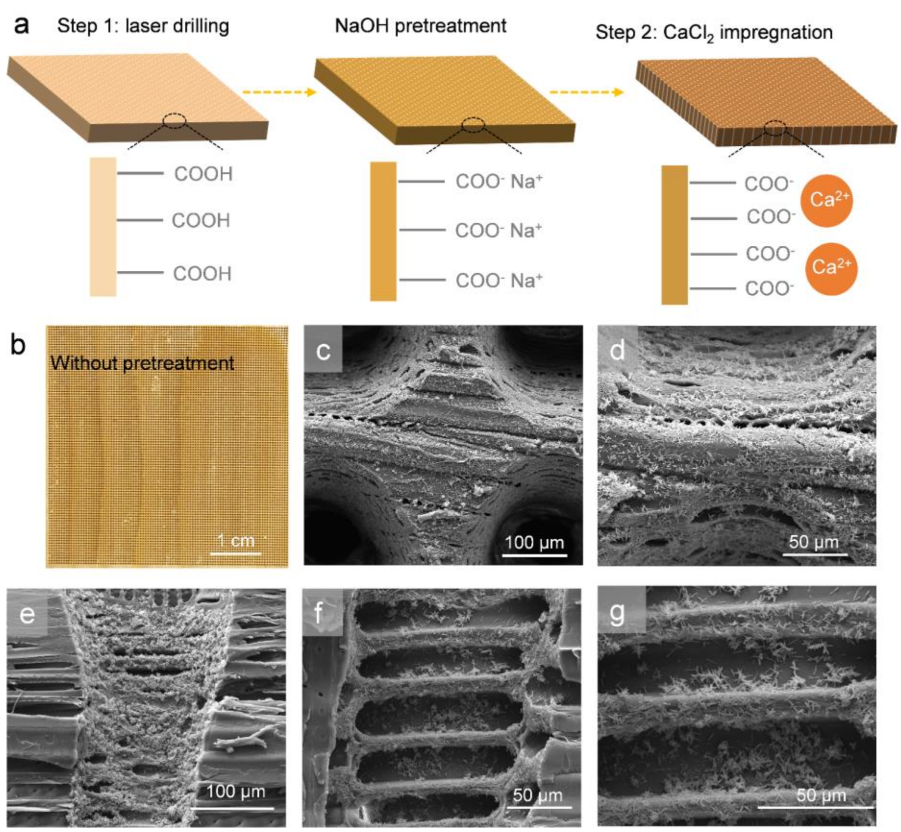

Fig. S4 (a) Schematic representation of the production steps for transpiring wood. After laser drilling, the lasered wood was pretreated by immersion in a 0.01 M NaOH aqueous solution and then with a $CaCl_2$ aqueous solution. (b) Photograph of a transpiring wood sample obtained without NaOH pretreatment. (c-g) SEM images of the transpiring wood sample without pretreatment. After drying, $CaCl_2$ migrated to the cell wall surface and crystallized, leading to a poor interaction with the wood matrix and leaching out.

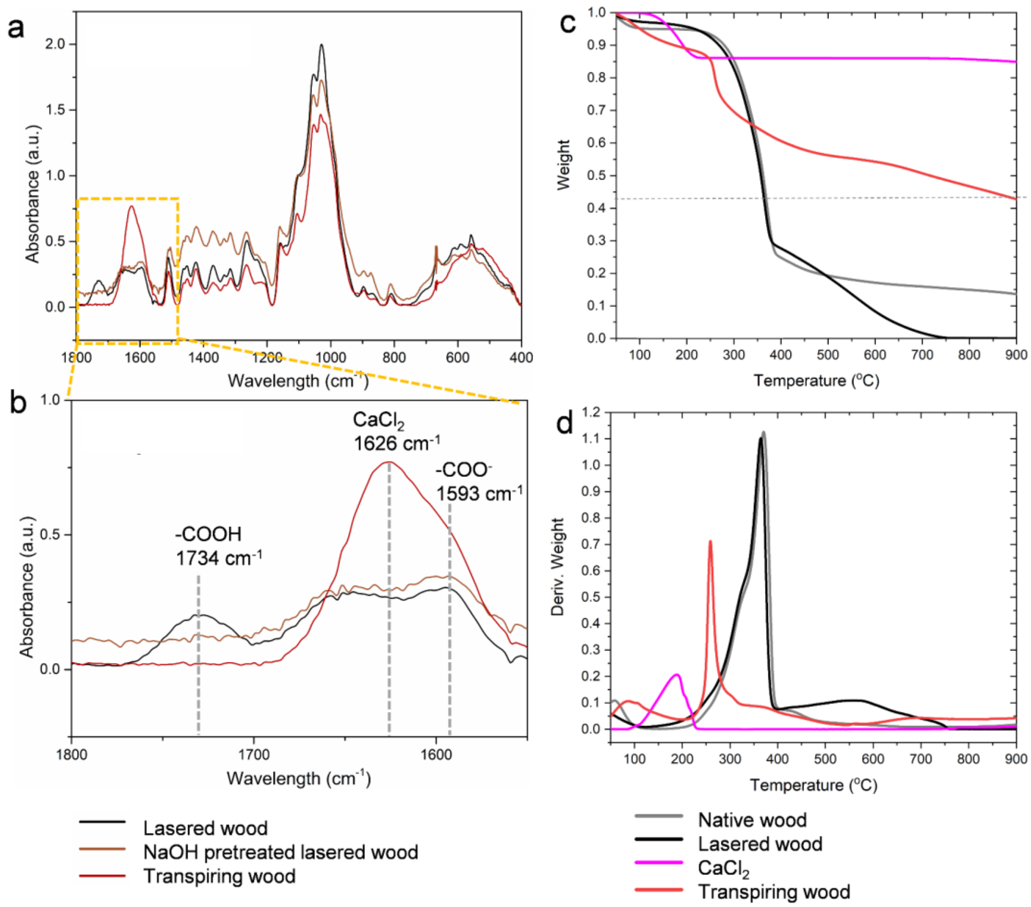

Fig. S5 (a-b) FT-IR spectra and (c-d) Thermogravimetric analysis (TGA) curves.

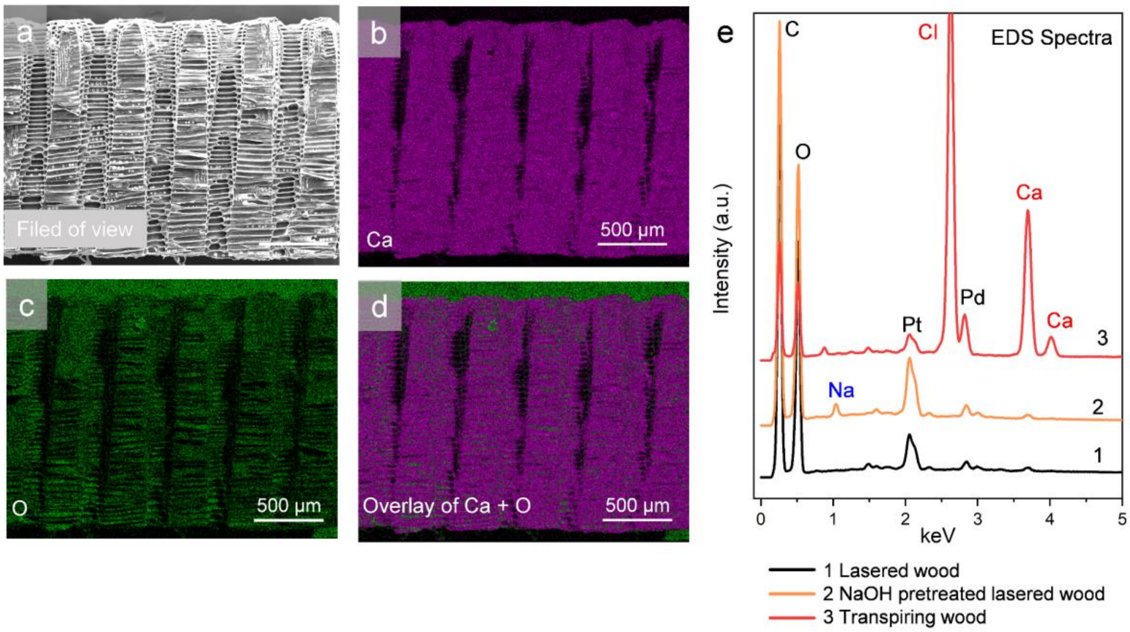

Fig. S6 (a-d) Energy dispersive X-ray spectroscopy mapping images of transpiring wood showing the successful loading and uniform dispersion of $CaCl_2$ in the wood scaffold. (e) Energy dispersive X-ray spectroscopy spectra of lasered wood before and after NaOH pretreatment, and of transpiring wood.

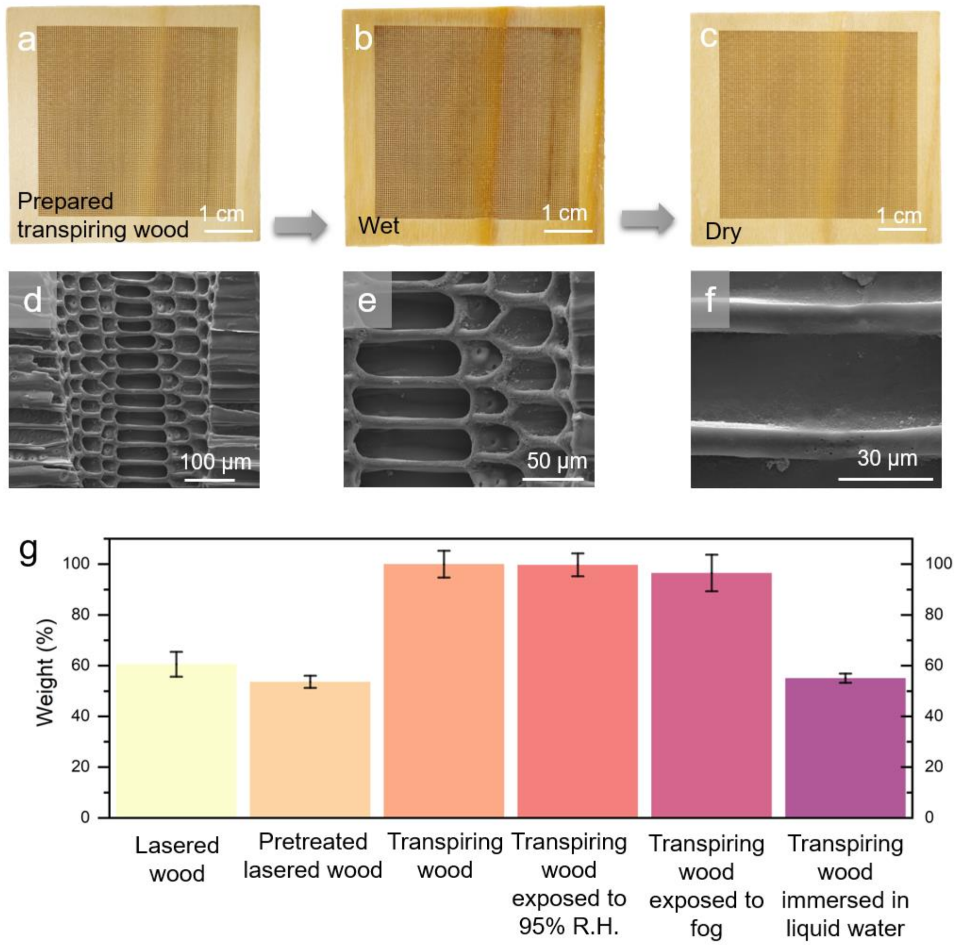

Fig. S7 Moisture stability of transpiring wood. (a-c) Photographs of (a) a freshly prepared transpiring wood sample, (b) the same sample after being exposed to 95% R.H. for 24 hours (water-saturated) and (c) after drying. (d-f) SEM images of the water-saturated sample. (g) Weight change of samples after processing steps and after being exposed to 95% R.H., fog, and immersion in liquid water.

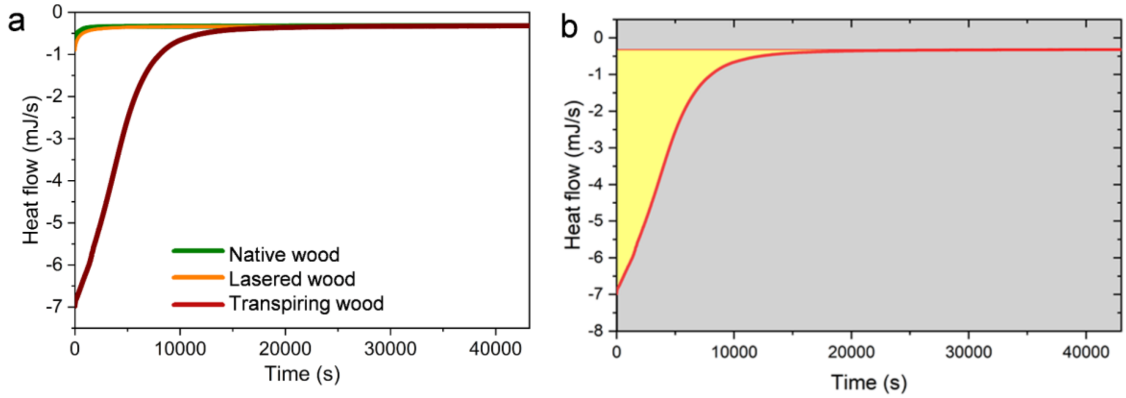

Fig. S8 (a) DCS curves and (b) latent heat of desorption calculation method. The yellow area is the integration of heat flow over time, which is the energy consumed in moisture desorption stage. The integrated area (unit in mJ) divided by sample weight (unit in mg) is the latent heat of water phase change from bound water to water vapor.

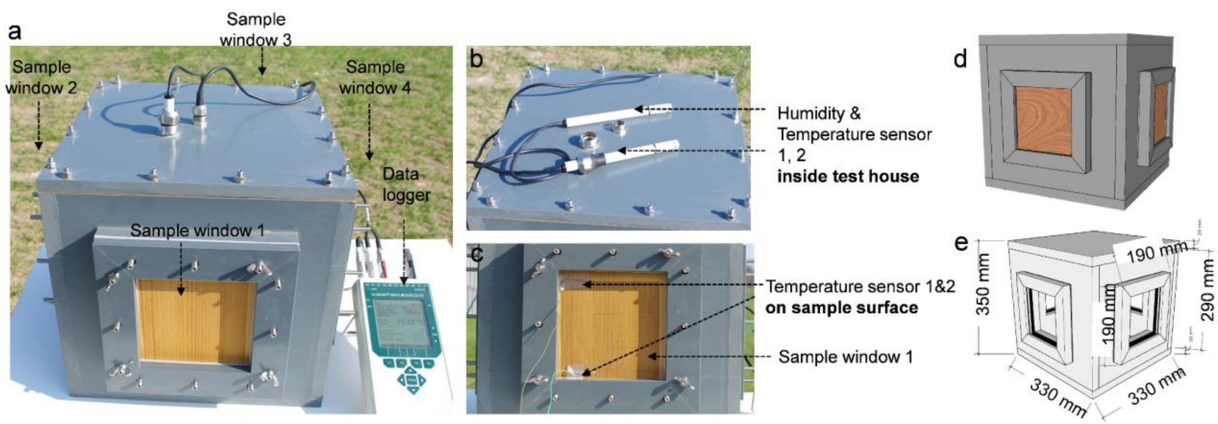

Fig. S9 (a-e) Setup for climate regulation measurements.

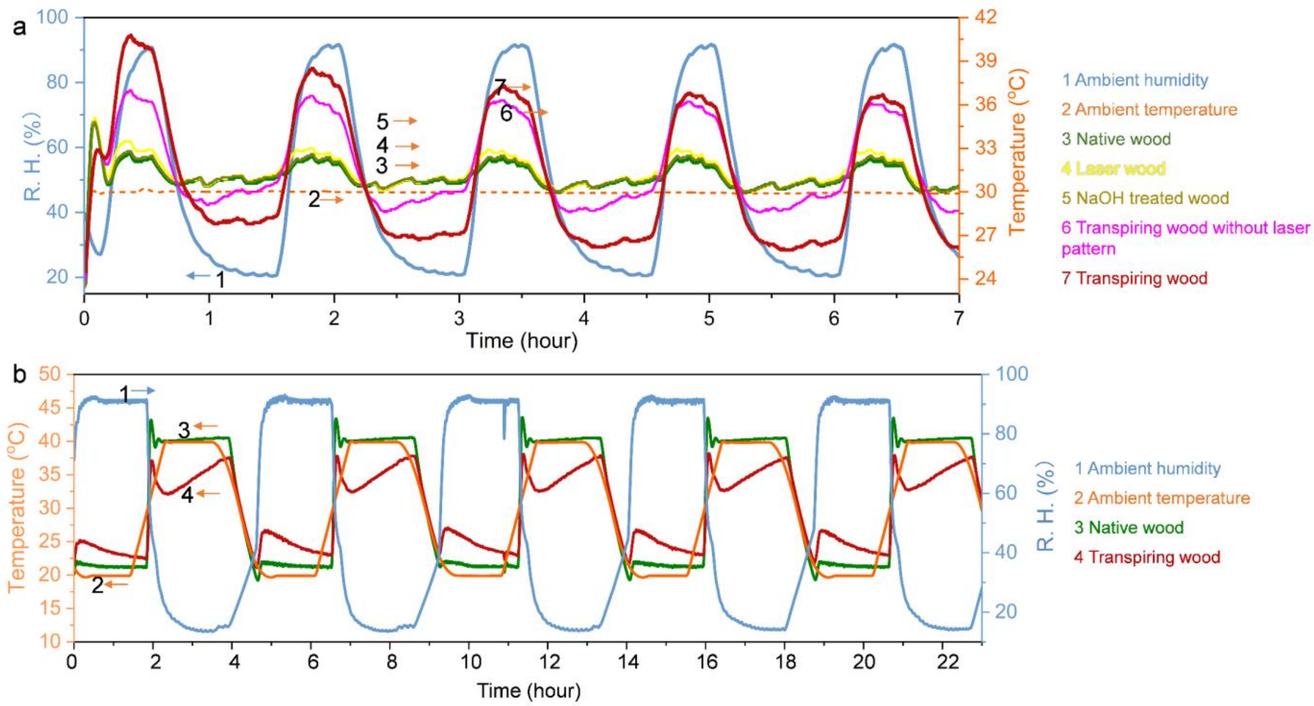

Fig. S10 (a) Surface temperature changes resulting from the application of dynamic humidity changes from 20%-90% R.H. at 30ºC, 5 cycles. (b) Surface temperature changes subjecting to dynamic humidity/temperature changes from 20ºC, 90% R. H holding for 1.5 hours, 40ºC, 20% R. H holding for 3 hours, 5 cycles.

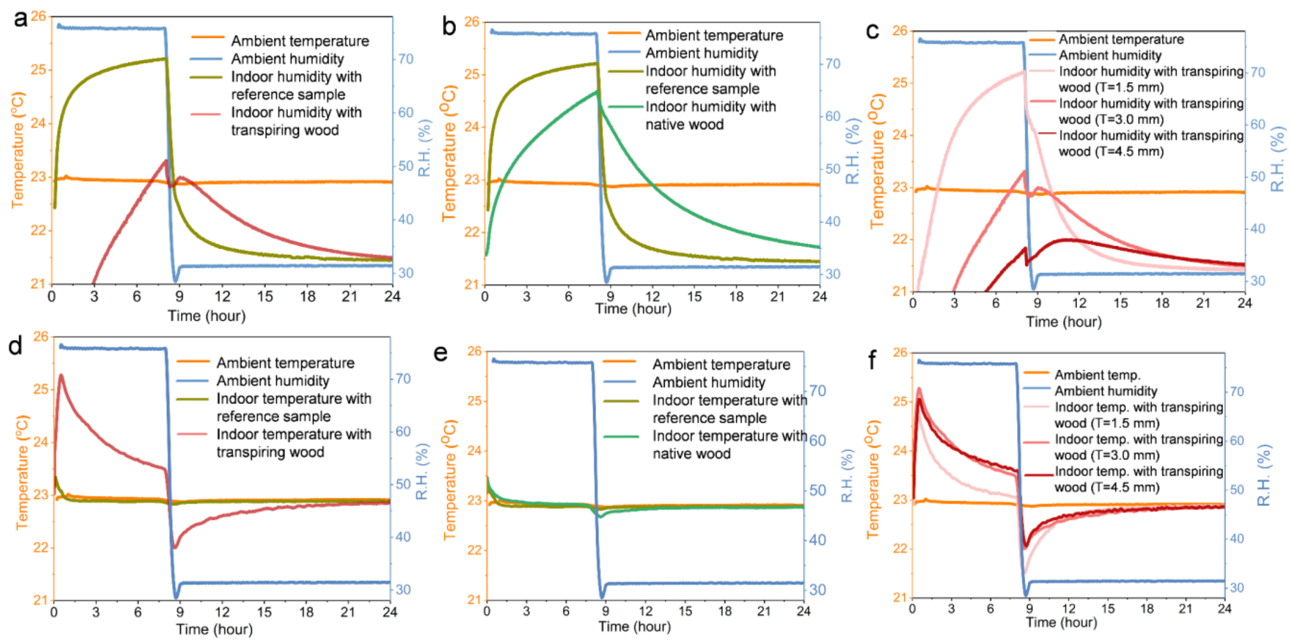

Fig. S**11** (a-d) Humidity regulation performance and (e-h) temperature regulation performance achieved using a reference sample, native wood, and transpiring wood with different thickness values.

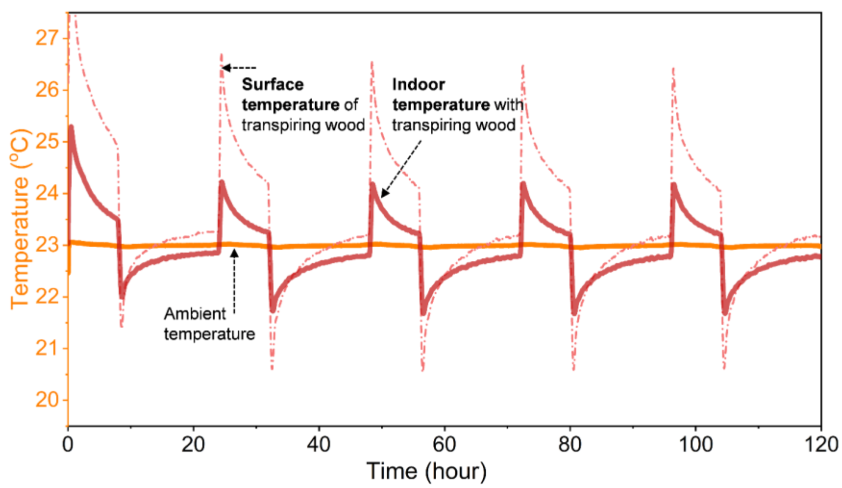

Fig. S12 Temperature regulation cyclic test: surface temperature of the transpiring wood, and indoor temperature with transpiring wood walls.

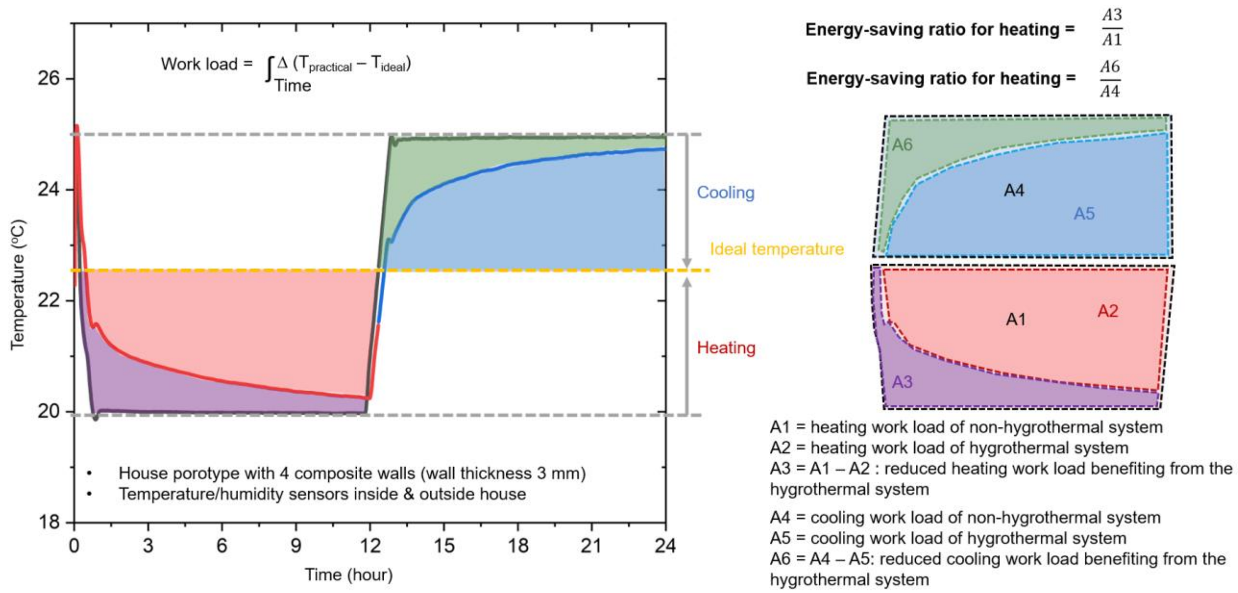

Fig. S13 Energy-saving ratio calculation method.

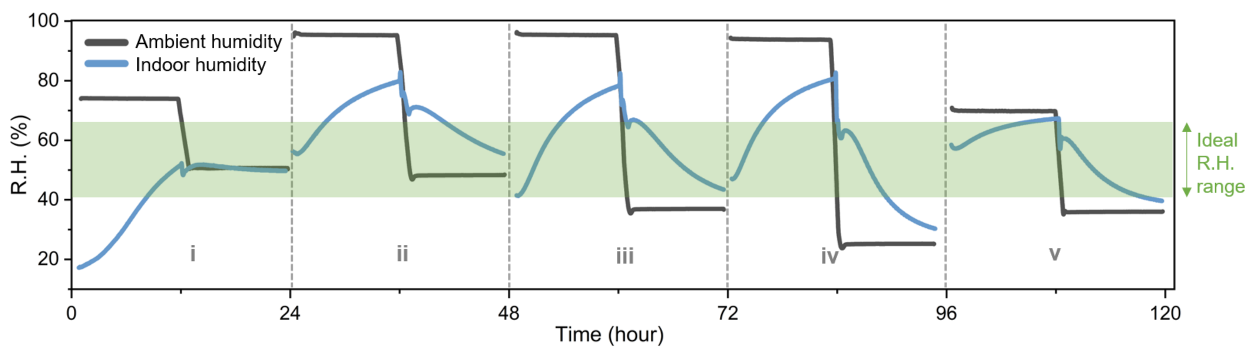

Fig. S14 Ambient and indoor humidity of the test house with transpiring wood walls under different test conditions. (i) night time: 10^{o}C, 70% R.H., 12 hours; day time: 15^{o}C, 50% R.H., 12 hours. (ii) night time: 15^{o}C, 90% R.H., 12 hours; day time: 25^{o}C, 50% R.H., 12 hours. (iii) night time: 15^{o}C, 90% R.H., 12 hours; day time: 30^{o}C, 40% R.H., 12 hours. (iv) night time: 20^{o}C, 90% R.H., 12 hours; day time: 40^{o}C, 30% R.H., 12 hours. (v) night time: 25^{o}C, 70% R.H., 12 hours; day time: 35^{o}C, 40% R.H., 12 hours.

Table S1 Ultimate tensile stress of samples after processing steps

Samples	Tensile strength (MPa)
Native wood	77.6 ± 9.9
Lasered wood	24.1 ± 4.7
NaOH pretreated lasered wood	47.9 ± 11.2
Transpiring wood	23.6 ± 6.8

Table S2 Samples density

Sample name	Density (kg/m^{-3})
Native wood	455.8 ± 41.2
Lasered wood	387.3 ± 31.1
Transpiring wood	646.2 ± 52.4
$CaCl_2$	2150

Table S3 Measured moisture buffer valwood-based based materials and pure $CaCl_2$.

Sample name	MBV ($g\ m^{-2}\ R.H.^{-1}$)
Native wood	0.78 ± 0.20
$CaCl_2$	39.27 ± 10.78
Wood-$CaCl_2$ composite without laser drilling	9.99 ± 1.71
Transpiring wood	13.82 ± 2.32

Table S4 Ranges for practical moisture buffer value classes

MBV $_{Practical}$ class	Minimum MBV level	Maximum MBV level	Materials and their MBV
	$g\ m^{-2}\ R.H.^{-1}$		
Negligible	0	0.2	Poly(methyl methacrylate)
Limited	0.2	0.5	Cement, 0.4
Moderated	0.5	1.0	Gypsum, 0.6; Perlite, 0.7; Wood, 0.8
Good	1.0	2.0	Rock wool, 1.1; Cellular concrete 2.0
Excellent	2.0	…	Glass wool, 2.1; Lime-hemp, 2.4; Cellulose, 4.0; Transpiring wood, 13.8

Table S5 Calculated latent heat of desorption of moisture-saturated samples.

Sample name	area (mJ)	weight (mg)	latent heat (J/g)
Native wood	466.55	7.5	62.2
Lasered wood	666.71	4.04	165.0
Transpiring wood	37946	18.44	2057.8

Table S6 Input and output of the production steps of the transpiring wood.

Input / Output	Quantity	Unit
Step 1: laser drilling		
Input		
Spruce wood	0.73	kg
Electricity (EU-28+3)	1	MJ
Output		
Lasered wood	0.62	kg
Wood dust	0.11	kg
Step 2: NaOH pretreatment		
Input		
Lasered wood	0.62	kg
NaOH	0.002	kg
De-ionized water	5	kg
Output		
NaOH treated wood	0.54	kg
Chemically polluted water	5.082	kg
Step 3: $CaCl_2$ impregnation		
Input		
NaOH treated wood	0.54	kg
$CaCl_2$	0.46	kg
De-ionized water	1.53	kg
Output		
Transpiring wood	1	kg
Chemically polluted water	1.3	kg

Note: Reference elementary flow of the International Reference Life Cycle Data System (ILCD).

Table S7 Data used for comparison of the environmental impacts of our transpiring wood with different materials.

Materials	**Dataset used**	**UUID**
Glass wool	Production of glass wool in the form of insulation materials that has the density between 10 to 100 kg/m^3.	898618b8-3306-11dd-bd11-0800200c9a66
Wax	Production of 1 kg of wax which is mainly composed of paraffins. The dataset includes material and energy inputs, as well as the production of waste and emissions from the production of n-paraffins out of crude oil. Water consumption and infrastructure have been estimated.	697889d5-d952-45eb-9e46-c39046c35522
Poly(ethylene glycol)	Polyester resin, production mix, at plant, esterification and polymerization, from propylene glycol, phthalic anhydride and styrene, 1.22- 1.38 g/cm^3.	92cbc76f-c535-440a-8724-c4395cefdedd
Poly(urethane)	Poly(urethane) rigid foam, production mix, at plant, from methylene diisocyanate (MDI) and polyols, 18- 53 kg/m^3.	1dfca12a-63dc-43bf-9263-cdfe3c972d89

Note:

Used database: Environmental Footprint database

All impact indicators are calculated based on 1 kg of material.