

PASSIVE HOUSE ENVELOPE QUALITY AND BUILDING PHYSICS

Airtightness, thermal insulation, thermal bridges, condensation, ventilation, cost-in-use and windows

ZEPHIR training session | Train-the-Trainers pilot programme (Day 3)

Dolni Rakovets (Bulgaria), 28 September to 2 October 2026

Dr. Phys. Francesco Nesi | ZEPHIR Passivhaus Italia

OUR DAY: FIVE TEACHING BLOCKS

The ZEPHIR day (Day 3 of the week) | 60% practical / 40% theory | approx. 7 teaching hours

1

Theory input (1.5 h, theory)

Airtightness and n50; thermal insulation; thermal bridges; condensation and mould; ventilation; cost-in-use; windows. This deck supports this block.

2

Guided demonstration (1.5 h, practical)

Blower Door test (Method A vs B); leak detection with smoke; airtightness taping. Not slides: live demo.

3

Hands-on group task (2.0 h, practical)

Seal a window-reveal mock-up; analyse a thermal-bridge and condensation case; size ventilation. Not slides: group work.

4

Reflection and discussion (1.0 h, theory)

What failed, what worked, which principle it proves, how to teach it to craftsmen.

5

Output planning (1.0 h, mixed)

Each trainee drafts a micro-lesson and a craftsman checklist; link the digital resources.

WHERE THIS DAY FITS: THE WHOLE WEEK

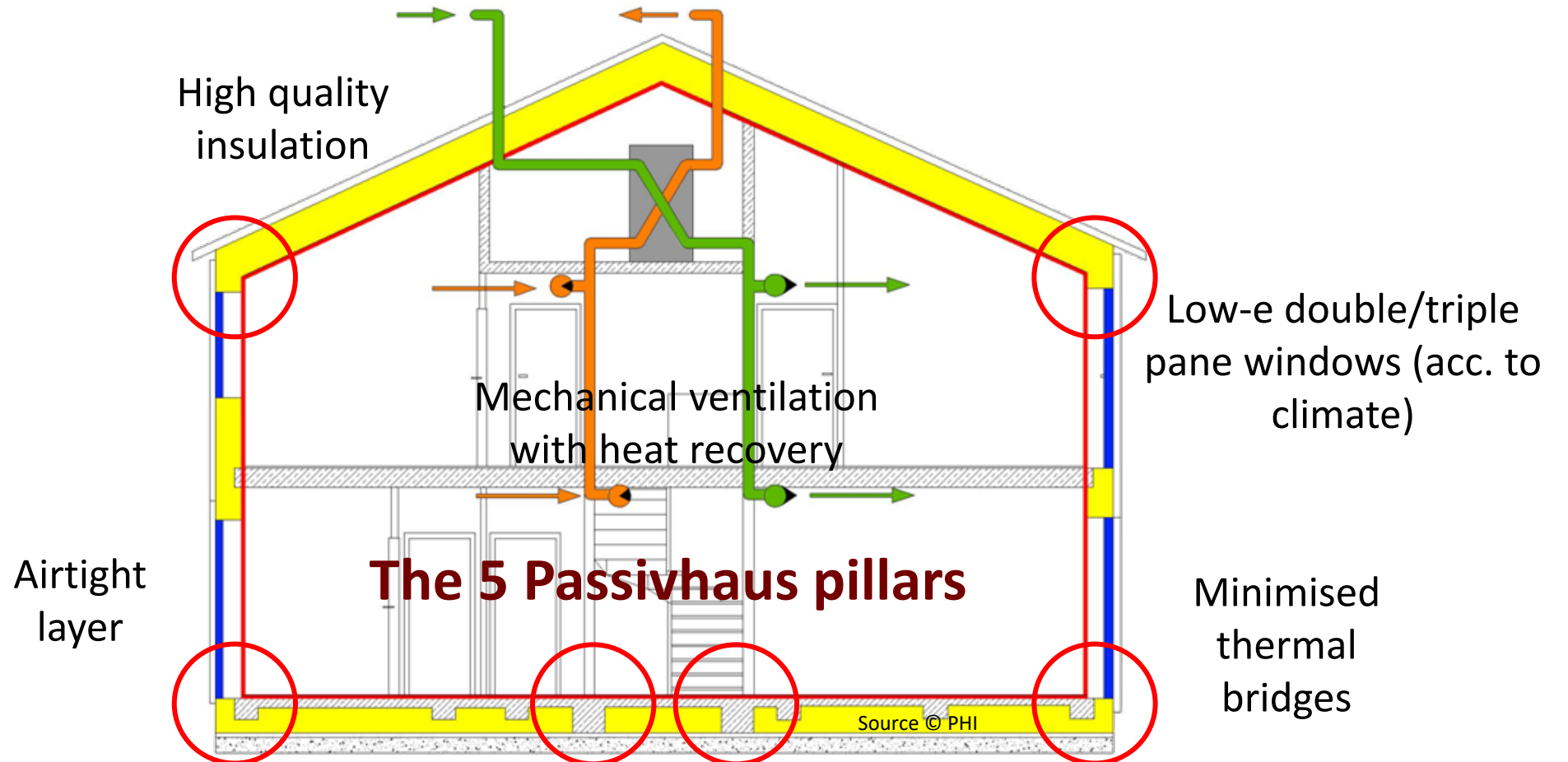
Five themed days, each led by the responsible partner. ZEPHIR leads Day 3 only.

Day 1	Program framework and teaching method
Day 2	Sustainable materials and application
Day 3	Passive House envelope quality and building physics (ZEPHIR)
Day 4	LCA / EPD, standards and documentation
Day 5	Integration, content plan and deadlines

You lead Day 3 only. On Days 1, 2, 4 and 5 you and your three trainees participate in the sessions led by the other partners; you do not prepare those days.

The 5 Passivhaus principles

Details matter!



SECTION 1

Airtightness

Why it matters, how n50 is measured, and how to build it

Why airtightness matters

- **One continuous air barrier around the whole heated volume**

An uncontrolled leak wastes heat and can drive moisture into the wall, where it condenses and feeds mould.

- **Airtight does not mean unhealthy: it means controlled**

An airtight envelope is always paired with mechanical ventilation, so fresh air is delivered by design.

- **It is measured, not assumed**

The Blower Door test gives an objective number, n50, that either meets the target or does not.

n50 targets by standard

Standard / label	n50 limit (h-1 at 50 Pa)
Passive House	≤ 0.6
CasaClima (Italy) Gold	0.6
CasaClima (Italy) class A	1.0
CasaClima (Italy) class B	2.0
German EnEV, with MVHR	1.5
German EnEV, without MVHR	3.0
Italian general building regulation	no legal limit

n50 = complete air changes per hour at 50 Pa, roughly the wind pressure of a 15 to 35 km/h wind on a wall.

The number to remember: n50

0.6

Passive House limit (h-1 at 50 Pa)

This is the limit: n50 must be at or below 0.6. A real ZEPHIR building measured 247 m³/h of leakage in a 492 m³ heated volume, so $n50 = 247 / 492 = 0.5$, which passes. Monitored ZEPHIR projects average around 0.37, best cases 0.26 and even 0.07.

Airtightness and vapour openness are not the same

- **Airtight to air, but open to vapour diffusion**

Stop air leakage (which carries a lot of moisture fast) while still letting the wall dry by slow vapour diffusion.

- **Vapour resistance is $sd = \mu \times \text{thickness}$**

In cold climates order the layers so resistance decreases toward the outside, so moisture that enters can escape outward.

- **Why it matters for craftsmen**

A wall that is airtight but cannot dry will still fail. The barrier controls air; the layer order controls drying.

Airtightness: materials and errors

The four airtight materials

Interior plaster (in masonry)

Wood sheathing, or vapour control membrane, or reinforced paper (in timber)

Concrete, the only intrinsically airtight structural material

Everything else needs a deliberately installed air barrier.

Common execution errors

Tape on a dirty or damp surface will not bond

A fold in the membrane is a leak, even if the material is airtight

Improvised junctions are neither durable nor airtight

Insufficient contact area: use semi-transparent tape to verify

Seal corners and junctions in the planned sequence

SECTION 2

Thermal insulation

Materials, U-value, and adapting thickness to climate

Insulation materials and the pencil rule

■ Continuous around the whole envelope

Walls, roof, ground floor and foundations: any gap in the insulation layer is a thermal bridge waiting to happen.

■ The Pencil Rule

You must be able to trace the insulation layer on a section drawing without ever lifting the pencil. If you cannot, there is a gap.

■ Material choice follows lambda, not marketing

Lower thermal conductivity (λ , W/(mK)) means better performance at the same thickness. Mineral wool, EPS, sheep wool, cellulose, cork and wood fibre are all viable; aerogel and vacuum insulation panels give a thinner layer at a much higher cost.

■ U-value is the target, thickness is the means

$U = 1 / R_{\text{total}}$. Halving U roughly doubles the thickness needed, so returns diminish once you are already in the Passive House range.

Adapt the envelope to the climate

Cold climates (continental Bulgaria)

Maximise insulation toward the upper Passive House range.

Never skip the floor.

Airtightness essential against condensation.

Warm-temperate and warm/semi-arid (Spain, central-south Italy)

Balance insulation with thermal mass and shading.

Ventilation also addresses summer comfort.

In hot/semi-arid: shading, mass and night ventilation take priority over insulation thickness.

Legal minimum vs Passive House (Italy, zone D)

Envelope element	Italian law (D.Lgs. 311/2006)	Passive House target
External wall	$U = 0.36$, 10 to 12 cm	$U < 0.25$, 10 to 15 cm
Roof	$U = 0.32$, 7 to 12 cm	$U < 0.25$, 10 to 15 cm
Ground floor slab	$U = 0.70$, 0 to 4 cm	$U \leq 0.65$, 2 to 6 cm
Windows	$U = 2.4$	$U \sim 1.2$

U-values in $W/(m^2K)$. Size the extra insulation from the gap. Heat-loss split: walls ~40%, roof ~25%, windows ~25%, floor ~10%.

SECTION 3

Thermal bridges

Where insulation is interrupted, heat takes a shortcut

What is a thermal bridge

- **A local area where heat escapes faster than the surrounding surface**

At corners, balconies, foundations, or where the insulation layer is interrupted.

- **Linear (psi) and point (chi)**

Linear in $W/(mK)$, point in W/K . Total loss = $\sum(U \times A) + \sum(\psi \times L) + \sum(\chi)$.

- **Thermal-bridge-free means $\psi_e \leq 0.01 W/(mK)$**

Teaching image: a ψ of just $0.2 W/(mK)$ is like leaving 1.80 m of building height uninsulated all around.

Real impact: Darmstadt Kranichstein

Junction	psi without care	psi with care
Window to wall	0.12	0.00
Partition wall to basement ceiling	0.628	0.061
External wall to basement ceiling	0.371	-0.039
Wall to roof	0.053	-0.061
External wall corner	-0.062	-0.062

Without thermal bridge reduction the extra loss is about 15 kWh/(m²a), the entire heating budget of a Passive House. Negative psi values are correct, from the external-dimension convention.

SECTION 4

Condensation

Surface temperature, mould, and vapour control

Surface temperature and mould

12.6

degC surface temperature threshold

At 20 degC and 50% humidity indoors, minus 10 degC outdoors: below 12.6 degC mould can grow (corners, behind furniture); below 9.3 degC the surface condenses, usually at the glazing edge. Passive House insulation keeps surfaces above 12.6 degC even behind furniture.

Vapour control: tight inside, open outside

■ Warm air holds more moisture

At 20 degC and 100% relative humidity, air holds 17.3 g/m³ of water vapour; at 50% RH indoors that is 8.65 g/m³. Where that air meets a cold surface below its dew point, the excess condenses.

■ Rule: resistance decreases toward the outside

The vapour control layer must be far more resistant to vapour than the layers beyond it, roughly 5 to 10 times, so any moisture that gets in can dry outward instead of being trapped.

■ A design decision, not an afterthought

A wall assessed for condensation risk at design stage avoids the retrofit fix later. This is the same logic behind the airtight-but-vapour-open layering from Section 1.

SECTION 5

Ventilation

Sizing MVHR with the hygienic rule

Mechanical ventilation with heat recovery

- **MVHR recovers up to 90% of the outgoing heat**

Passive House asks for at least 75% heat recovery efficiency on the air-to-air exchanger.

- **Hygienic sizing rule**

20 to 30 m³/h per person; never below 0.3 air changes per hour; extract 60 kitchen, 40 bathroom, 20 WC.

- **Filtration and ducts**

F7 filter on supply, G4 on extract, duct pressure loss under 15 to 20 Pa. Extract-only is not enough for Passive House.

Sizing: two worked examples

3 people / 85 m²

Supply demand: $3 \times 30 = 90 \text{ m}^3/\text{h}$

Minimum air change: $0.30 \times 85 \times 2.5 = 64 \text{ m}^3/\text{h}$

The higher value governs:

design at 90 m³/h.

2 people / 150 m²

Supply demand: $2 \times 30 = 60 \text{ m}^3/\text{h}$

Minimum air change: $0.30 \times 150 \times 2.5 = 112.5 \text{ m}^3/\text{h}$

The higher value governs:

design at 112.5 m³/h.

SECTION 6

Cost-in-use

Judge every choice over the whole building life

Cost-in-use: judge over the whole life

■ Running cost dominates

Operating, maintenance and reconstruction often exceed 80% of a building's total life-cycle cost.

■ Payback does not scale with investment size

In a real retrofit the largest measure paid back fastest (about 6 years), a mid-sized one took over 20.

■ Apply it to every choice

Stone wool costs 15 to 30% more than EPS but lowers fire and moisture risk; good airtightness needs almost no maintenance; MVHR saves heat but adds filter cost.

■ The rule

Compare simple and discounted payback, and whole-life cost, not just the construction budget.

Judging investment: three checks

Metric	What it tells you
Simple payback	Investment divided by annual saving, in years. Easy to compute, ignores the time value of money.
Discounted payback (NPV)	Same idea, but future savings are discounted to today's value. More realistic, always longer than simple payback.
Internal Rate of Return (IRR)	The discount rate at which the investment breaks even, $NPV = 0$. Compare it to your cost of capital: higher IRR is better.

Rule: never authorise a measure on the construction budget alone. Compare simple and discounted payback, and IRR, over the whole building life.

SECTION 7

Windows

Frame, glass and installation quality decide real performance

Window energy balance

■ Balance, not just insulation

Energy balance = transmission losses + ventilation losses, minus solar and internal heat gains recovered. U-value and g-value (solar factor) are the two dominant terms.

■ Low-e coating and gas fill cut U_g

A low-emissivity coating plus argon, xenon or krypton fill between panes lowers the glazing U-value (U_g) well below plain double glazing.

■ Frame matters as much as glass

U_w combines frame (U_f) and glazing (U_g) weighted by area; the glazing edge spacer also affects performance, not just the frame material or the glass.

The comfort limit

0.85

U_w in $W/(m^2K)$

Below this whole-window U-value, occupants stop feeling a cold radiant surface near the glass or a downdraft in winter. It is a comfort threshold as much as an energy one: humans feel uncomfortable when surfaces around them radiate at very different temperatures.

Window requirements by climate zone

Climate zone	Typical glazing	Max Uw installed [W/(m2K)]
Arctic	Vacuum or low-e, 4 panes	0.45
Cold (continental Bulgaria)	Low-e, 3 panes	0.65
Cool-temperate / alpine (Italy)	Low-e, 2 to 3 panes	0.85
Warm-temperate (coastal Italy, Spain)	Low-e, 2 panes	1.3
Warm / hot	2 panes, anti-sun coating	1.6 to 2.9
Extremely hot	3 panes, anti-sun coating	1.3

Source: PHI / SEEDPass project data. Not monotonic: in warm and hot climates solar control (g-value, shading) matters more than the U-value alone, so read this as glazing strategy, not a single ranking.

Installation decides half the performance

	Recommended installation	Poor installation
Psi_install [W/(mK)]	0.005	0.15
Effective Uw [W/(m2K)]	0.78	1.19

Same window, same glazing. The only variable is installation detailing: taped, thermal-bridge-free reveal versus a gap sealed with foam alone. Effective performance drops by more than half.

Thank you.

Every detail shown here is a detail you will teach a craftsman.

State the problem, give the principle, show the wrong and the right example,
let them practise by hand, test it, document it.

Dr. Phys. Francesco Nesi | ZEPHIR Passivhaus Italia | f.nesi@zephir.ph | passivhausitalia.com

Funded by the European Union. Views and opinions expressed are those of the author only and do not necessarily reflect those of the European Union or EACEA. Neither can be held responsible for them.