Passivhaus and EnerPHit Certification Criteria

Q_H	**Heating (& Cooling) Demand** (Additional Cooling Demand allowed for some climates). Amount of fuel/energy needed to heat the building for one year.	**≤ 15 kWh/(m2a)** Passivhaus (aim for ≤ 13 kWh/(m2a) max.) **≤ 25 kWh/(m2a)** EnerPHit
or P_H	**Building Heating (& Cooling) Load**	**≤ 10 W/m2** Passivhaus (for cool temperate climate)
PE	**Primary Energy Demand** (non-renewable). Average efficiency of getting 1kWh/(m2a) to the house connection, averaged across the whole world.	**≤ 105 W/m2** Classic only. Plus and Premium have to use PER.
PER	**Primary Energy Renewable Demand** per m2 of ground (building footprint). Can have ±15 kWh/(m2a) deviation between PER demand and Renewable en. gen. In PH, PER demand incl. all house appliances.	**≤ 60 kWh/(m2a)** PH/EP Classic **≤ 45 kWh/(m2a)** PH/EP Plus **≤ 30 kWh/(m2a)** PH/EP Premium
Renewable Energy Generation	Energy generation criteria for Passive Haus.	**≥ 60 kWh/(m2a)** PH Plus **≥120 kWh/(m2a)** PH Premium
n_{50}	**Air-tightness** (number of air changes per hour at 50Pa.	**≤ 0.6 1/h @ 50Pa** Passivhaus **≤ 1.0 1/h @ 50Pa** EnerPHit
Excess temperature frequency	Also **Comfort Limit** or **Frequency of overheating**. Space specific. Percentage of hours in a calendar year with indoor temperatures above 25 °C.	**≤ 10%** EnerPHit & PH Always aim for much less (2% in UK/Ireland) and stress test.
Φ_{HR}	**Heat recovery efficiency** (amount of heat recovered from total heat exhausted expressed as %)	**≥ 75%**
Φ_V	**Electrical efficiency** of ventilation unit	**≤ 0.45 W/(m3/h)**
Electricity demand for Ventilation	Enegy consumption per unit of volume.	**max 0.45 Wh/m3**

Passivhaus Measurement Terms and Factors

TFA

Treated Floor Area **m2**

Floor area of rooms within the thermal envelope with a head height of 2m or more **EXCLUDING** internal walls, doors, stairs, lifts, openings, columns (higher than 1.5m), chimneys, door and window recesses if 12cm or less deep, areas with less than 1m head height and risers.

Areas counted at 60%: Auxiliary rooms outside of dwellings/ in basements, areas below stair. Heated access hall outside flat.

Areas counted at 50%: Rooms with height between 1 and 2m, ie parts of understair spaces.

Form Factor

Form Factor
Unitless

Envelope area (m2) divided by TFA (Treated Floor Area) (m2)

The lower the form factor the less insulation needed to meet Passivhaus standards.

L

Length
Metres

For Passivhaus used in thermal bridge and area calculations.

External dimensions are always used.

EA

Exposed Area
m2

In PH used in thermal bridge and area calculations. External dimensions of the thermal envelope are always used (if a ventilated cavity is present then the materials are excluded).

V_{n50}

Tested (internal) volume
m3

Volume of air inside the measured building calculated by multiplying the net floor area by the net ceiling height.

NOT INCLUDED:
- Floors and walls
- Dropped ceilings
- Window niches

INCLUDED:
- Staircases

COP

Coefficient of performance
Factor - unitless

For every unit of energy you put into the heat pump you get 2.7 units of energy out.

A_F

Internal floor area
m2

As used for air-tightness testing/calculations.

A_E

External envelope area
m2

As used for air-tightness testing/calculations.

η

Eta = Utilisation/Safety factor
Unitless, Range between 0 and 1

The higher the proportion of heat gains, the lower the factor. Provided by PHPP.

Passive House Economics

Annuity Factor - Loan

Annuity Factor is the multiplier used to determine how much money will be paid out on the annuity (loan) contract.

-n = negative power of n
i = interest rate in decimal
n = length of loan

$$AF_{loan} = \frac{i}{1-(1+i)^{-n}}$$

PVF and AF are inverse of each other so it is easy to work one out from the other.

$$AF_{loan} = \frac{1}{PVF} \qquad PVF = \frac{1}{AF_{loan}}$$

Annuity

Use when given additional principle (P) that you have to borrow to build a PH project and want to know what the annual mortgage repayments will be.

$$A = P \times \frac{i}{1-(1+i)^{-n}}$$

i interest

A: Annuity **Chosen Currency**

P: Additional principal (money) you have to borrow

↓ AF **Annuity Factor (AF) for loan**

Nominal vs Real Interest Rates

Nominal growth of money is part devalued by inflation. What remains is the real money growth that corresponds to an inflation rate of 0%. This calculation is used to eliminate the uncertain inflation rate when making economic comparisons thereby using real price increases and real interest rates.

$$i_{real} = \frac{1 + i_{nominal}}{1 + r} - 1$$

i_{real} = real interest rate

$i_{nominal}$ = nominal interest rate

r = inflation rate

Present Value of Future Cash Flows

Method used to calculate how much additional borrowing (mortgage) can be funded by annual energy savings. It is worth stress testing the calculation for higher interest rates.

$$PV = C \times \frac{1-(1+i)^{-n}}{i}$$

PV = How much you can borrow to be no worse off; Present Value **Chosen currency**

C: Annual Energy savings **Currency**

PVF: Present Value Factor

-n = negative power of n
n = Duration of mortgage in years

i = Mortgage interest rate expressed in decimals. 1% = 0.01

Static amortization

Simple payback calculates the number of years within which the investment would be paid back. Rarely sufficient to assess cost impact of measures as it misses out life span and other factors. Not the appropriate method for appraisal of long-term investment.

Cost of a Saved kWh Calculation

Calculation of how economically viable PH components for refurbishment are in relation to the cost of 1kWh. Ie. each measure will have a cost per saved kWh. The measure is profitable if the P_{SAVED} (£/kWh) (cost to purchase 1 kWh of energy) is lower than $P_{ENERGY\ COST}$ (£/ kWh) (cost to save 1kWh of energy).

Present Value (P_{SAVED} = cost to save 1kWh of energy.

AF = Annuity Factor for the length of the loan (annuity per year)

I_{add} **= Additional investment/cost required** to meet PH standard

R = Residual value of component after the end of the loan term.

Z = Annual maintenance cost resulting from introduction of the PH measure.

E_{saved} = Amount of energy saved as a result of the PH measure **kWh/a**

$$P_{SAVED} = \frac{AF_{loan\ term} \times (I_{additional} - R) + Z}{E_{saved}}$$

Currency/kWh

Residual Value

What is the economic value of a PH measure once the loan has been paid off. In other words, the residual value of a component/measure after the end of the loan term

$$R = [1 - (AF_{product\ life} \times PVF_{loan\ term})] \times I_{additional}$$

Annuity Factor - Product Life

$$AF_{product\ life} = \frac{i}{1-(1+i)^{-n}}$$

n = Product life in years not length of loan

Passive House Renewables

Renewables in Passive House

Not mandatory for PH Classic but mandatory for Plus and Premium. Only **solar photovoltaic and wind power generatio**n are considered renewable in PH as they generate energy.

Heat pumps and solar thermals and biomass and biofuels are not renewable in PH.

Data sources: Mosart Passive House course (November 2023)
Passive House Institute (December 2023)

Building - Construction Materials, Components and Composites (construction build ups)

λ

Lambda
Thermal Conductivity
W/(m*K)

Rate of heat transfer through the material with a nominal thickness of 1m and a ΔT of 1K across the material.

$$\frac{\text{W * m thickness}}{\text{m2 area *K}}$$

R-Value

Thermal Resistance
m2K/W

A measure of resistance to heat flow through a given thickness of material.

$$= \frac{1}{\text{U-value}}$$

Rsi

Internal Surface Film Resistance
m2K/W

Downward/ floors (incl. unheated basement ceiling): **+0.17 m2K/W**

Horizontal/ walls: **+0.13 m2K/W**

Upward/ roofs: **+0.10 m2K/W**

Rse

External Surface Film Resistance **m2K/W**

All ext. exposed surfaces: **+0.04 m2K/W**

Below ground exterior surfaces: **+0.0 m2K/W**

Ceiling into unheated attic/ void: **+0.10 m2K/W**

Unheated basement ceiling/floors: **+0.17 m2K/W**

U-value

Thermal transmittance
W/m2K

Rate of heat transfer through an element of assembly.

How much energy (W) moves continuously through one m2 of surface area with a 1 degree temperature (K) difference between faces.

Radiant Temp. Assymetry

Units: °C

Radiant temperature = temperature of surrounding surfaces. An asymmetry occurs when the temperature radiant difference in various directions is more than 4.2 °C as that is when humans feel discomfort. (5 °C in other sources)

χ

Chi value
W/K

Chi is a measure of energy (W) lost per 1 degree temperature difference. Point thermal bridges. Multiple point thermal bridges are added together and divided by the surface area they are located in to get a an overall (W/m2K) value.

ψ

Modelled in the Areas sheet in PHPP.

Psi value
W/(mK)

Psi is energy (W) lost per m of thermal bridge per 1 degree temperature (Kelvin) difference. Linear thermal bridges.

Excellent ψ: **0.10 W/mK to +0.01 W/mK**
Acceptable ψ: **Less than +0.04 W/mK**
Poor ψ: **+0.04 W/mK to 0.10 W/mK**
Terrible ψ: **+0.10 W/mK upwards**

Negative ψ value to ≤ 0.01 W/(mK) is considered thermal bridge free under Passivhaus criteria. This should be the aim. Negative Psi values are an artefact of double counting junctions due to measuring external planar area rather than internal. There is no negative Psi value in physics, it is a strategy for compensating the double-counting.

f_{Rsi}-value

Hygiene criterion/ Health factor/ Temperature Factor. **Unitless, ranging from 0 to 1.**

The temperature factor fRsi defines the coldest point which can occur on the interior surface of a construction system. Determines risk of mould or condensation

fRsi 0 = internal surface temperature at thermal bridge same as outside
fRsi1 = internal surface temperature at TB same as rest of house = no TB
Healthy fRsi ≥ 0.7 in cool temperate climates has to be over 0.7.

$$f_{Rsi} = \frac{T_{si} - T_e}{T_i - T_e}$$

Tsi: Internal surface temp; Te: external air temperature; Ti: Internal air temp

Y-factor

Thermal bridge penalty (heat loss) of the project (linear and point TBs). **W/m2K**
How much energy (W) moves continuously through one m with a 1 degree temperature (K) difference between faces.

Y-factor = impact of thermal bridges on building performance. Y-factor of 0.2 W/m2K is applied generically as a penalty to every single U-value for SAP calcs if none has been provided.

$$Y = \frac{\Sigma(\psi \times L)}{EA}$$

Y: Y-factor **Wm2/K**; Σ: Sum of all individual losses through TB; ψ: Psi value W/(mK); L: Length (m); EA: Total Exposed Surface Area of the building using internal measurements (m2)

Thermal bridge

Thermal bridges:

- **Linear repeating** TB (ie. studs) - get calculated within U-value
- **Linear construction** TB - corners, construction changes etc. (Psi value)
- **Point** TB (ie. anchors, columns, ties etc) (Chi value) - goes into the U-value calculation

Impact: Mould, interstitial or surface condensation, heat loss.

Calculation for PH based on external dimensions, for Building Standards based on internal dimensions. There is a conversion in PHPP for this.

$$\text{Material thickness (m)} = \frac{\lambda}{\text{U-value}}$$

Determine material thickness from U-value and thermal conductivity:

$$\Delta U = \frac{\text{Increased loss W/K}}{\text{Area of element where heat loss will be offset m2}}$$

Determine improvement in U-value required based on element area and additional heat loss:

Typical thermal conductivity

Metals	
Aluminium (Anodized)	237 W/mK
Steel - Galvanized Sheet (0.14% C)	62 W/mK
Steel - Mild	40 W/mk
Steel - Stainless	17 W/mK
Concrete	
Concrete (2% steel) DIN	2.5 W/mK
Concrete Reinforced	2.06 W/mK
Cement Plaster	1.6 W/mK
Conventional concrete blocks	0.7-0.13 W/mK
Gypsum board	0.25 W/mK
Autoclaved aerated concrete blocks	0.12-0.19 W/mK
Wood	0.13 W/mK
Insulation	
Foamglass	0.058 W/mK
Wood fiber	0.043 W/mK
Diasen insulating paster	0.037 W/mK
Cork	0.036-0.040 W/mK
Mineral wool	0.034 W/mK
Cellulose	0.034 W/mK
Rockwool	0.033 W/mK
EPS (Silver)	0.031 W/mK
PIR	0.022 W/mK
Vacuum insulated panels	0.007 W/mK

Typical Passive House U-values

OPAQUE ELEMENTS	Warm climate	Cool temperate	Cold Climate
Wall	0.25-0.5 W/m2K	0.15 W/m2K	0.12 W/m2K
Floor	0.30 W/m2K	0.15 W/m2K	0.11 W/m2K
Roof	0.17 W/m2K	0.10 W/m2K	0.09 W/m2K
Maximum U-value **opaque elements**	0.50 W/m2K	0.15 W/m2K	0.12 W/m2K
TRANSPARENT ELEMENTS			
PH U_W-install	1.25 W/m2K	0.85 W/m2K	0.65 W/m2K
PH U_W-glass	1.20 W/m2K	0.70 W/m2K	0.52 W/m2K
PH U_W-frame	1.20 W/m2K	0.80 W/m2K	0.61 W/m2K
PH U_W-window	1.20 W/m2K	0.57 W/m2K	0.57 W/m2K
Maximum U-value **transparent elements**	1.20 W/m2K	0.8 W/m2K	0.6 W/m2K

ψ glass spacer

Good Psi_{sp} value	2 W/mK	0.027 W/mK	
Bad Psi_{sp} value		0.30 W/mK	

Typical non PH Window U-values

Single glazing	5.8 W/m2K
Double glazing 4/12mm air/4	2.9 W/m2K
Double glazing 4/20mm air/4	2.8 W/m2K
Double glazing 4/16mm air/4	2.7 W/m2K
Triple glazing - no insulating gasses	2.00 W/m2K
Double low-e 4/16mm Argon90%/4	1.3 W/m2K

Thermal Comfort

The following affects the thermal comfort of people:

- **Air temperature** - PH optimum 20 °C and stratification less than 2 °C between head and ankles of a person.
- **Air velocity** - high velocity is perceived as draft. Prefered less than 2/m.
- **Exterior humidity** - this can affect internal humidity especially during cold weather (low humidity) or in humid climates in cooling season.
- **Thermal equilibrium** of human body - Radiant temperature not in assymetry.
- **Surface temperature**: no lower than 15.8 °C on vertical surfaces and 18 °C on floors.
- **Relative humidity** - optimum between 35-55%

Windows

PH windows

"Passive House quality" windows have an **insulating efficiency resulting in θair - θsurf temperature ≤ 3.5 °C**. under the coldest design conditions. Typically triple glazed, fitted with low-e glazing and filled with Argon or Krypton to prevent heat transfer. G-values around 50%.

PH frames can be made of aluminium as long as they are appropriately thermally broken. **Glass spacers** should never be aluminium in PH. Stainless steel is acceptable but polymeric material is best.

Glass is more thermally efficient than the frame. **The lower the frame to glass ratio the better for window performance.**

g-value

Solar Heat Gain Coefficient of glass. **Unitless. Value 0 to 1** (0 = 0% solar heat can enter = opaque material;1 = 100% solar heat transmission). **The lower, the less heat gain.**

Proportion of solar/heat energy available for a space/transmitted through glass. G-value reflects building location, orientation and climate. In northern Europe, g-value would typically be 0.5 or higher. Ranges between 25-62% reduction. The more panes of glass the lower the solar gains.

G-value often needs to be lower for W than S-facing windows as they are harder to shade and so typically at higher risk of overheating.

Typical G-value range for triple glazed south facing window is 0.5-0.63 in cool temperate climate.

Gasses in glazing

Argon: Common gas (9,300 PPM in atmosphere); 25% more dense than air, better insulator by 34%; inert gas, low reactivity

Krypton: More expensive, denser than argon, better insulator (63% denser than air), inert gas, low reactivity.

Xenon: More expensive again. 79% better insulator than air.

Shading

Fraction of shading measured by PHPP for winter and summer sun in given location.

Reduction factor for shading (under Radiation balance in PHPP):

- Unshaded: approx. 1
- Rural/suburban areas: approx. 0.7
- Inner city, large roof overhangs: approx. 0.4

The height of a shading object is measured from the bottom of the glass for each window/door.

Reduction Factor z

In PHPP this is where you can enter temporary sun protection through retractable blinds and awnings.

Shading from side reveals in PHPP is entered under ^{o}reveal' and '^{d}reveal.

Energy balance of a PH window

Sum of energy loss and solar energy gains through windows. Result may be net loss or net gain.

$$Q_{H\ window} = Q_S - Q_T$$

$Q_{H\ window}$: Energy balance of window **kWh/a**; Q_S: Solar heat gains **kWh/a**; Q_T: Heating transmission losses **kWh/a**

ISO for Windows

U-value of glass:
ISO EN 673

U-value of window frames:
ISO EN 10077-2

Data sources: Mosart Passive House course (November 2023)
Passive House Institute (December 2023)

Climate/ Environment/ Location

RH or ϕ

Relative humidity of air: **Unit %**

Amount of moisture in the air compared to maximum the air can hold. Varies with temperature, hence relative. Expressed as a % of the maximum amount that air could hold at a given temperature.

Ideal RH is 50%. If RH is high we like it to be cooler, if low we like the temperature to be higher.

Optimal RH range 35-55%. Target RH range 35-60% indoors. With an increase in temperature the RH drops because warm air can hold more water vapour than cold air.

f_t

Temperature Factor
Unitless.

Insulating effect of soil factor. Location specific. Used in Q_T calculations. Omitted for windows.

Above ground = 1

Below ground = varies by location.

G_t

Heating Degree Hours **(kKh)/a**

Values per location/tables.The higher the value the more extreme the climate. Reflection of how many hours per year and by how many degrees it is below 20 degrees in a given location and month or year.

$$G_t = \Delta T \times Days \times 0.024$$

- G_t: kKh/ month or annum
- ΔT: Temp. diff. btw 20 °C in and aver. temp. out for chosen month. If per annum, add all 12 mths of ΔTs together.
- Days: No. of days in month or 365 for year.
- 0.024: 24 hours divided by 1000 to get kh

PER Factor

Regional Primary Energy Renewable Factor.
Unitless. Provided by PHPP based on location.

Varies by country/climate/area. PER-factor reflects the primary renewable resources needed to cover the final energy demand of a building, including distribution and storage losses. A PER-factor of 1.5 means a surplus of 50% renewable primary energy is needed to be able to meet the final energy demand at the building. **The higher the PER-factor, the higher the required resources.**

$\Delta T_{1 \text{ or } 2}$

Delta Temperature
Units: °K (degrees kelvin)

Temp. difference between inside (20 °C) and outside in sunny+cold (1) and cloudy+mild (2) weather. PHPP calculates both and more onerous value is used in Yearly Heating Degree Hours calculation.

Psychrometrics

Study of physical and thermodynamic properties of gas-vapor mixtures expressed as

Mould needs 80% RH to grow. In a 20°C environment with 50% RH, surfaces at **12.6 °C will lead to mould** (the surface temperature at which the RH rises to 80%).

Condensation occurs on surfaces at 9.3 °C in a a 20°C environment with 50% RH.

Domestic heating and hot water

Hot air ventilation

Hydronic heating system or a post heater. Post heater is installed after the MVHR unit for suppy air that is already pre-heated from the heat exchanger. Maximum 52 °C (dust burns higher °C).

Heated ventilation can only be delivered as a sole solution when heat load ≤ 10W/m2. For higher P you either need supplementary heating or a different heating strategy.

Temperature sensors to be installed:

- In a suitable reference room (ie. living room or corridor in the centre of dwelling)
- Away from direct sunlight and other sources of heat or cold that could distort readings (stove, kitchen, etc)
- In a visible location.

Amount of energy from 1l of oil = 10kWh.

Hot water/heating pipes

Use short runs, especially outside thermal envelope. Insulation thickness should be 1.5-2x diameter of pipe (min 2x dia. for heating). Insulation has to be continuous over fittings, taps and pipe clips. Non-vapor-tight insulation on hot water pipes inside the thermal envelope is fine.

Domestic Hot Water

Energy use largely dependant on occupants and water efficient taps, shower heads and appliances and system efficiency. Use smallest dia. of pipe possible - quicker supply, less energy loss. Keep single pipes (twigs) as short as possible.

DHW generation options: **Boiler, heat pump, solar thermal or electric resistance**.

Legionella risk: Bacteria that multiplies in water of temperature between 20-45 °C, especially stagnant water. Water needs to be stored at 60 °C and distributed at 50 °C (with mixer valve to prevent scald) to prevent Legionella. Flush out rarely used outlets. Can also prevent growth through ionisation and biocide treatments.

Heat load capacity calculation for Hot air supply heating

$$P_{air\ heating} = V_{Flow} \times \Delta T \times C_{air}$$

- $P_{air\ heating}$: **Watt (W)** Capacity for delivering heat via ventilation air. Divide by TFA for specific heat load (W/m2).
- V_{Flow} (MVHR): Ventilation flow rate **m3/h**. Use normal flow rate **23m3/ per person per hour** not 30m3/ ppph for Boost.
- ΔT (Environmental conditions): Temp. difference between HRV supply air and max. heat from post heater/coil. **°K**
- C_{air} (Environmental conditions): Heat carrying capacity of air. **W/m3K**. Constant at **0.33 W/m3K**

Domestic Hot Water Energy Calculation

$$Q_{DHW} = V_{Flow} \times time \times \Delta T_{water} \times C_{water} \times 365$$

- Q_{DHW}: **kWh/a** Annual energy required for DHW use.
- V_{Flow} (HW Demand): Volume of water flow per minute **l/m**
- time (HW Demand): Time of hot water running. **Minutes**
- ΔT_{water} (Environmental conditions): Temp. difference between cold water and hot water supply **°K**
- C_{water} (Environmental conditions): Specific heat capacity of water. Constant **0.001162 kWh/ litreK**
- 365: days/y

Building - Air-tightness and Ventilation

n50

Air-changes per hour
1/h@50Pa (or ACH/ h@50Pa or h^{-1})

Number of air changes per hour at a pressure of 50Pa (circa 20mph wind) used as a measure of air-tightness.

n50 for PH ≤ 0.6 1/h@50Pa (max. 0.649 ACH/ph before rounding).

For PH both pressurasation and depressurization values must be presented in Airtightness test results. Final result is average of both. Difference should not be big. If it is there is an issue with windows and doors.

q50

Air-permeability
m3/(hm2)@50Pa

How many m3 of air pass throughone square metre of surface area in one hour.

Used in Building Standards. Max. ranges between 5m3 to 10m3.

$$q50 = V_{50} / EA_{n50}$$

EAn50 = Building Envelope Area

For PH, large buildings need to be tested for both n50 and q50. It is much easier to get a low air change figure with large buildings (air volume larger than 4000m3) than a small building.

q50 for PH ≤ 0.6 m3/(hr m2) Larger buildings should be much better than the limit.

w50

Air leakage
m3/(m2h)

Comes up in air-tightness testing/reports. Not really used elsewhere.

$$w50 = \frac{V_{50}}{TFA}$$

Sd Value

Vapour resistance/tightness
m thickness of air

Material resistance to vapour diffusion in comparison to a meter thickness of air. The higher the Sd value the more vapour tight/closed/resistant.

eg. Sd value 0.4-60m_{air} for Vapour variable membrane. Ranges from vapour open at 0.4m_{air} resistance to vapour closed/resistant at 60m_{air}.

C_{air}

Heat carrying capacity of air
Wh/(m3K)

Constant 0.33Wh/(m3K)

Amount of heat a m3 of air can carry.

Coefficient 'e'

Normalisation of atmospheric losses
Unitless

Fraction of air changes per hour at normal atmospheric pressure.

Buildings normally operate at 0 presure so Infiltration losses identified in Air-testing need to be normalised to normal atmospheric pressure through Coefficient 'e'.

Average air leakage rate
Wind exposure adjustment

Wind adjustment	Space Heating Demand	Heat Load
No protection to building:	**0.1 (10%)**	**0.25 (25%)**
Moderate protection: (most projects)	**0.07 (7%)**	**0.18(18%)**
High protection:	**0.04 (4%)**	**0.10 (10%)**

Btw. heating demand and heat load the difference is x 2.5 (exaggerates infiltration losses by 2.5).

V_{n50}

Volume of air for air-tighness testing/ Tested (Internal) Volume
m3

Net floor area (not TFA!) **x real net ceiling height**. Same for residential and commercial. Interior dims used. Also called **blower door volume**.

INCLUDED
Wardrobes and built-in areas
Stairs
Spaces less than 1m high

NOT-INCLUDED
Window and door niches
Dropped ceilings
internal floors and walls

A_F Floor area
A_E Envelope Area

Door blower test

- Wind speed must be less than 6m/s
- Temperature difference between inside and outside must be no grater than 10 °C.

ISO for Caulk

DIN 4108-11 - min. req. for durability of bond strength with adhesive tapes and adhesive masses used for establishment of air-tight layers.

Airtightness in PH

Airtightness is one of the fundamentals of Passive House (PH). It is vital for energy efficiency (thermal loss is limited), thermal comfort (no drafts) and for protecting the building fabric from damp and mould (together with good ventilation). It is measured through a blower door test and must be **≤ 0.6 1/h@50Pa** to meet PH criteria.

Ventilation in PH

Mechanical ventilation in PH is always with heat recovery (MVHR) as that is the fundamental principle for reducing thermal loss in heating and cooling. In order to enable air flow between air in and air out spaces doors need to be undercut by 30mm or suitable door frame or wall vents need to be used (these are preferable as they can provide acoustic attenuation.

Kitchen extract

Whilst useful for getting rid of oils and vapour from cooking it is not necessary to turn-on the exhaust hood in a PH as the exhaust air is running on a continuous basis. If needed the ventilation Boost function can be turned on for a limited time to clear any smells. If a kitchen extract is used in a domestic setting it should be recirculation only. In a commercial kitchen the extract needs it's own air supply so as not to unbalance the ventilation system and will present a large thermal loss.

$n_{V\text{-}}$ demand

Effective air change rate (1/h or ACH). Natural infiltration rate + un-recoverable air change rate of the mechanical system since it's never 100% efficient.

Data sources: Mosart Passive House course (November 2023) Passive House Institute (December 2023)

PH Certification Criteria for MVHR

Upper and lower limits of operational range:

Min. 3 controllable levels: Set-back (54%), Normal/ Standard (77%) and Boost (100%)

Airtightness testing pressures between 50 Pa and 300 Pa. Leakages ≤ 3% at mid-flow range.

Heat recovery efficiency according to PHI method tested at 100 Pa, ≥75% at outdoor temperatures between -15 °C and +10 °C.

Constant flow rate fans, imbalance <10%

Target air speed 2m/s for efficiency and acoustics. Main trunk branches can increase to max. 3m/s.

Electrical consumption for all fans and controls at upper limit of operational range ≤ 0.45 W/(m3/h) at nominal flow rate (with frost protection disabled).

Protection for heat exchanger - must guarantee continuous operation. Pre-heater must switch in at -3 °C or less (tested for 12 hours at -15 °C.

Frost protection shutdown for downstream hydraulic heater coils

Comfort criterion - minimum supply air temperature of 16.5 °C at external -10 °C

Max. supply air temp after supply air heating coil 52 °C. Dust particles begin to smoulder and smell above that.

Maximum standby losses (when in purely stand by mode) of 1W

Automatic restart after power failure

Hygiene - easy inspection and clearing of central aparatus and homeowner able to change filters

Filters - outdoor air ducts must accommodate an F7 filters, g4 on extract air.

Max noise emission from the ventilation into living space in PH MVHR is 25dB

Locating MVHR unit

For efficiency MVHR unit should be located:

- Inside thermal enclosure
- Near external envelope to minimise length of cold air ducts
- Comfortable height and access for changing filters
- Plenty of room for condensate drain to bottom

Ventilation Ducts

Ventilation ducts should be **sturdy, air-tight and allow smooth flow. Suitable materials are metal (galvanised steel, aluminium o rstainless steel) or plastic (HDPE).**

Avoid flexible ducting where possible, especially for long runs. Flexible ducts kink very easily which can constrict air flow, increase turbulence and noise and increase fan power to supply the air flow rates required.

Exception is flexible duct connections to MVHR unit which with sound attenuators are essential to neutralise noise from infiltrating vents.

Duct insulation

Ventilation ducts between MVHR (within insulated envelope) and the outside (penetrating the thermal envelope) must have **vapour closed (diffusion resistant) insulation** as there is a risk of condensation. **50-100mm** (typically 100mm, 25mm ok in some instances).

If **MVHR is outside thermal enclosure, all ducts need to be insulated** until inside the thermal envelope.

Heated suppy air ducts outside thermal envelope should have **100-150mm of insulation**.

Supply air ducts inside only neeed to be insulated **if they deliver heating or cooling (post heated/cooled ducts)**. Typically **25mm**, can be vapour open as within heated envelope.

Upstream = against air flow direction
Downstream = with direction of air flow

MVHR intake and exhaust

Outdoor air intake

- **Must be clean and fresh** - stay away from parking areas, alleys, boiler or dryer exhausts, dryers etc.
- **Should be located ≥ 3m above ground** where possible.

Exhaust air

- Must not be too near windows or other air intakes. Check building standards.

Intake and exhaust

- Intake and exhaust points should be kept min. 1.5m apart.
- Louvres or vent caps have to be fitted to keep out wind-driven rain and rodents. Must not be too restrictive. Very fine mesh will clog up over time.
- Easy access important for regular checking

MVHR pressure losses

Transferred air pressure loss must not exceed 1.00 Pa.

Typical pressure losses highest to lowest:

- External air filter F7 - high efficiency filters can be the single highest pressure loss in a ventilation system. Increased surface area lowers the loss.
- Supply air jet nozzle
- Disc valve 100mm
- Pipe bend 90°
- Pipe bend 45°
- Spiral seam duct, round, straight

Ventilation duct diameter calculation

$$\text{Duct diam.} = 2 \times \sqrt{V / (\text{Velocity} \times \pi \times 3{,}600)}$$

Duct diam.	2	V	Velocity	π	3,600
m multiply by 1000 to get mm duct size.	Constant conversion factor	Ventilation flow rate **m3/h**	Target velocity Constant **2m/s** (**Min. 1.5 m/s**, **Max. 3 m/s**)	Pi **3.14**	Conversion factor for seconds to hours

Compact Ventilation Unit

Heating, ventilation and domestic hot water all in one appliance. Only fresh air is required. Can be used where heat load doesn't exceed 10W/m2 (ie. PH).

If more is required, various solutions for generating heat/cooling are available:

- Exhaust Air Heat Pump: heating, cooling and dehumidification function.
- Small condensing boiler (gas based) - heating only
- Small biomass heat generator - heating only

Heating only versions - limitations:

SUITABLE for cold and cold temperate climates, especially cold and dry climates. Less risk of freezing as thre is little condensate. Better efficiency in cold temperatures than an HRV.

NOT SUITABLE for warm and humid climates. It also cannot meet demand for cooling in a warm climate.

MVHR speeds

1. **Low/set back** - at least 30% less power than standard
2. **Standard** (outdoor air requirement to standard occupancy)
3. **Boost:** at least 30% more than standard.

Increasing flow rate reduces efficiency of HR system.

Sound

Silencers - install at supply and extract outlets. Needed for exhaust and intake if environment very noisy.

Cross talk silencers - install between bedrooms, study and other rooms which need to be extra quiet and between ventilation unit and quiet space.

MVHR Filters

Recommended air filters:

- **F7** - ePM2.5/Pollution filter for outdoor air ducts
- **G4** - Standard recommended/Dust filter for extract air.
- **M5** - Pollen/Summer

$C0_2$

Carbon dioxide **PPM (parts per million) carbonic acid**

Air Quality Indicator: CO2 concentration **≥ (equal or higher than) 1,000 parts per million** it is considered bad for humans.

PH sets out typical CO2 per activity levels. This sets a **min of 30 m3/h air change per person for very good air quality.**

Enthalpy Recovery Ventilator

ERV - An enthalpy/energy exchanger is an air-to-air heat exchanger that additionally transfers moisture from one stream to another. Humidity is therefore kept at a consistent level, removing risk of excessive dryness. Both the thermal and the latent energy are recovered.

During the warmer seasons, an ERV system pre-cools and dehumidifies; during cooler seasons the system humidifies and pre-heats.

Coanda Effect (Surface effect)

Tendency of a fluid to be attracted to a nearby surface parallel to the direction of flow. In practice, when air is supplied at one end of the room it travels across the room/ceiling naturally, distributing the air, without need of ducting into the space.

Sensible cool/heat-ing

Sensible heat is heat you can sense/feel and can be measured by a thermometer.

Latent cool/heat-ing

Latent heat is hidden heat/energy which is involved in a change of elemental state (solid to liquid, liquid to gas and vice versa).

Building - Ventilation and MVHR for Calculations

Ventilation air change rate

Min air change rate per hour **1 air change or ACH/h or h^{-1}** $= \frac{\text{V- Flow rate}}{V_V}$

Air changes per hour delivered by the ventilation system at normal atmospheric pressure during normal building use. Different to airtightness pressurised air changes rate (max. 0.6@50Pa).

PH: **Min. is 0.39 1/h x V_V at Boost. 0.3 1/h (ACH) at Standard.** No. of changes required to maintain healthy air. Higher the ACH rate = drier air.

PH Ventilation Zones

- Supply Zones (Bedrooms, living spaces)
- Transfer Zones (Circulation spaces)
- Extract Zones (Bathrooms, kitchens, WCs, stores)

V_{SU}

Volume of supply air **m3/h**

Volume of air that gets supplied into living spaces (living rooms, bedrooms and studies) by MVHR.

Supply and extract air must be in balance. Check flow rates.

V_{EX}

Volume of extract air **m3/h**

Minimum extract air volume is prescribed by room.
20m3/h for each WC, store, laundry, etc
40m3/h for each bathroom/shower rm
60m3/h per kitchen

$V_{THROUGH}$

Volume of though air **m3/h**

Circulation spaces are through spaces between supply and extract areas in MVHR ventilation.

V_v

Ventilated volume for MVHR **m3**

TFA x 2.5m to get ventilation volume for residential. Actual ceiling height for other types of properties. **Reference volume for calculating air exchange rate** NOT air-tightness.

Heat recovery rate efficiency

Heat recovery rate efficiency **% percentage**

Percentage representation of amount of heat recovered from total heat exhausted. **PH limit ≥ 75% heat recovery. EnerPhit Limit ≥ 75-80% depending on climate.**

Penalty of 12% efficiency reduction is put on MVHR units that are not certified PH for residential buildings. Independent 3rd party verified data is required for non-certified commercial units.

V-Flow rate

Ventilation flow rate **m3/h for PH** but litres/ sec for SAP/DEAP/NZEB

Ventilation flow rate m3/h is equivalent to (V_V x n_V). Can be used if the two values are not given and worked out from occupancy of a building x 30m3/h.

Design air flow rate in PHPP is stated as a Boost value. The maximum is calculated as a sum of all extract air.

Conversion factors:
m3/h to l/s: x 0.2777
l/s to m3/h: x 3.6

PH Ventilation Flow Rates

Preferred air speed of ventilation system **2m/s**.

1. Min. total supply @100% fan speed: **Flow rate = no. of people x 30 m3/h pp**
2. Min total extract @100% fan speed: m3/h calculated **based on room requirements.** (extract room x flow rate) for each room added together
   - **20m3/h** for each WC, store, laundry, etc
   - **40m3/h** for each bathroom/shower rm
   - **60m3/h** per kitchen**.**
3. Min air change rate @100% fan speed: **0.39 1/h x Ventilated Volume**

Which ever result is highest defines the maximum capacity required for the MVHR system. **Units m3/h**. < 600m3/h is small capacity. > 600m3/h large capacity.

Data sources: Mosart Passive House course (November 2023)
Passive House Institute (December 2023)

Energy Balance Equations

A difference between heat losses and heat gains gives the required top up needed to achieve optimal comfort/temperature. The energy balance calculations demonstrate the principles and considerations for establishing heating demand and heating load and are at the heart of establishing a buildings operational requirements.

PHPP software figures out all the different factors upon information input. The difference between them has to be ≤ 15kWh/(m2a) for Heating Demand and ≤ 10 W/m2 for Heating Load.

Heating Demand

Q_H

Heating Demand/Quantity
kWh/(m2a)

Quantity of energy needed to maintain 20 degrees C throughout the entire heating/cooling season (calculated for every month of the year) in a particular climate within a particular thermal envelope and per m2 of TFA (Treated Floor Area).

kWh/m2a

kiloWatthour is the unit of energy expended over time. kWh/m2a is energy consumed per year with reference to 1m2 of the TFA.

To calculate heating demand limit for a Passive house building multiply TFA by PH limit of 15kWh/(m2a).

PassivHaus limit ≤ 15 kWh/(m2a)
EnerPHit limit ≤25kWh/(m2a)
Aim for 2kWh/(m2a) less

Heating Load

P_H

Heating Load/ Power
W/m2

Power of heating system needed to maintain 20 decrees C per m2 area of the building in a particular climate.

W/m2

Watt is the unit of power (the rate of energy being supplied). W/m2 is the rate of energy required per 1m2 of TFA.

To calculate heating load limit for a Passive House building multiply TFA by PH limit of 10 Watt.

PH limit ≤ 10 W/m2 peak demand

Window Heat Load Energy Gains

$$P_S = r \times g\text{-value} \times A_W \times G_{1,2}$$

- P_S – Solar heat gain **Watt (W)**
- r – Solar reduction factor **Unitless**
- g-value – Solar Heat Gain Coefficient **Unitless**
- A_W – Gross window area (incl. frame) **m2** Total for all windows and doors.
- $G_{1,2}$ – Global solar radiation **W/m2** Varies by climate and orientation

Heat Load MVHR Ventilation losses

Building element | Climate conditions

$$P_{V\text{-}MVHR} = V_V \times n_{V\ system} \times (1-\eta_{HRV}) \times C_{air} \times \Delta T_{1\ or\ 2}$$

- $P_{V\text{-}MVHR}$ – **Watt (W)**
- V_V – Ventilated Air Volume **m3** (TFA x 2.5m ceilings for domestic)
- $n_{V\ system}$ – **1/h** - No. of air changes per hour at normal ventilation speed.
- $(1-\eta_{HRV})$ – **Eta - Unitless/ Fraction** 1 minus efficiency of MVHR system. Rate that we are NOT recovering is inserted here.
- C_{air} – Heat carrying capacity of air **Wh/(m3K)** Constant **0.33Wh/m3K)**
- $\Delta T_{1\ or\ 2}$ – Temp. difference between inside (20 °C) and outside in sunny+cold and cloudy+mild weather. **Units Kelvin (K)** More onerous value used.

Heat Load Ventilation Air Infiltration losses

Building element | Climate conditions

$$P_{V\text{-}Infil} = V_{n50} \times e \times 2.5 \times n_{50} \times C_{air} \times \Delta T_{1\ or\ 2}$$

- $P_{V\text{-}Infil}$ – **Watt (W)**
- V_{n50} – Air tightness test volume as measured for PH. **m3**
- e – Coefficient e **% or decimal** Average leakage rate of 7% = 0.07
- 2.5 – Safety factor of 2.5 for windy weather
- n_{50} – Air-tightness test result **1/h@50Pa**
- C_{air} – Heat carrying capacity of air Wh/(m3K) Constant **0.33Wh/m3K)**
- $\Delta T_{1\ or\ 2}$ – Temp. difference between inside (20 °C) and outside. **Units Kelvin (K)**

Internal heat Gains

$$P_I = q_i \times A_{TFA}$$

- P_I – **Watt (W)**
- q_i – Specific Power **W/m2**
- A_{TFA} – Treated floor area **m2**

q_i = Average internal heat load when unoccupied. **1.6 W/m2** for residential projects.

Annual Space Heating Load Energy Balance Equation

Heating load losses | Heating load gains

$$P_H = P_T + P_{T\text{-}TB} + P_{V\text{-}Infil} + P_{V\text{-}MVHR} - (P_S + P_I)$$

- P_H – Heating Load/ Power **Watt**
- P_T – Heating transmis. losses **Watt**
- $P_{T\text{-}TB}$ – Transmission losses from thermal bridge **Watt**
- $P_{V\text{-}Infil}$ – Air Infiltration Ventilation losses **Watt**
- $P_{V\text{-}MVHR}$ – MVHR Ventilation losses **Watt**
- P_S – Safety Factor
- P_I – Safety Factor

Always comfort check for a space with large areas of glass

Power of heating system needed to maintain 20 decrees C per m2 area of the building in a particular climate. Watt is the unit of power.

$$P_{H\ specific} = \frac{P_H\ \text{Watt}}{A_{TFA}\ \text{m2}}$$

$P_{H\ specific}$ **W/m2**

$P_{H\ specific}$ ≤ 10 W/m2 for PH

Heat load adjustment due to Transmission losses

Building element | Climate conditions

$$P_T = A \times U \times \Delta T_{1\ or\ 2}$$

- P_T – **Watt (W)**
- A – Area of element **(m2)** measured on the outside.
- U – U-value of element **W/(m2K)**
- $\Delta T_{1\ or\ 2}$ – Temp. difference between inside (20 °C) and outside in sunny+cold and cloudy+mild weather. **Units Kelvin (K)** More onerous value used.

Both weather options are used as separate calculations - one formula with delta T1 and one with Delta T 2 for all the calculations. At the end the worst case scenario defines the heat load.

Heat Load Transmission losses due to Linear Thermal Bridging

Building element | Climate conditions

$$P_{T\text{-}TB} = L \times \psi \times \Delta T$$

- $P_{T\text{-}TB}$ – **Watt (W)**
- L – Linear thermal bridge length. **metres (m)**
- ψ – Psi value of TB element **W/(mK)**
- ΔT – Temp. difference between inside (20 °C) and outside.

When asked for **specific** heating load, divide result by TFA to get W/m2.

+

Heat Load Transmission losses due to Point Thermal Bridging

Building element | Climate conditions

$$P_{T\text{-}TB} = \# \times \chi \times \Delta T$$

- $P_{T\text{-}TB}$ – **Watt (W)**
- # – Number of point thermal bridges. **Unitless**
- χ – Chi value of TB element **W/K**
- ΔT – Temp. difference between inside (20 °C) and outside.

When asked for **specific** heating load, divide result by TFA to get W/m2.

Data sources: Mosart Passive House course (November 2023)
Passive House Institute (December 2023)

Heat Demand Ventilation Infiltration losses

$$Q_{V\text{-}MVHR} = V_v \times n_{v\ system} \times (1-\eta_{HRV}) \times C_{air} \times G_t$$

- $Q_{V\text{-}MVHR}$: **kWh/a**
- Building element:
  - V_v: Ventilated Air Volume **m3** (TFA x 2.5m ceilings)
  - $n_{v\ system}$: **1/h** - No. of air changes per hr delivered by MVHR system at normal flow rate.
  - $(1-\eta_{HRV})$: **Eta - Unitless** Efficiency of the HR system. Rate that we are NOT recovering is inserted here.
- Climate conditions:
  - C_{air}: Heat carrying capacity of air Wh/(m3K) Constant **0.33Wh/m3K)**
  - G_t: Yearly Heating Degree Hours. Values per location/tables. **(kKh)/a**

$n_{v\ system}$: Infiltration air change rate = $V_{Flow\ rate}$ (m3/h)/ V_V (m3). $V_{Flow\ rate}$ can be worked out as occupancy of a building x 30m3/h (Boost) per person if not given.

(Eta) Efficiency at 91% means an Eta of 1 - 0.91 so 0.9 is the figure that goes into the calculation.

MVHR Thermal Efficiency Calculation

$$\eta_{HRV} = \frac{(T_{ETA} - T_{EHA}) + \dfrac{P_{ELEC}}{(V_{Flow} \times C_{air})}}{(T_{ETA} - T_{ODA})}$$

- η_{HRV}: **Eta %** Efficiency factor
- T_{ETA}: Temp extract air
- T_{EHA}: Temp exaust air
- P_{ELEC}: Power of MVHR unit in Watt (W)
- T_{ODA}: Temp outdoor air
- V Flow = MVHR Flow rate for the building m3/h. C_{air} is constant at 0.33

Solar Reduction Factor calculation

$$r = \text{dirt} \times \text{irradiation} \times \text{shading fraction} \times \text{glazing fraction}$$

- dirt: 5% dirt obstruction = 0.95 factor. % of window NOT obstructed by dirt.
- irradiation: Generally 15% reduction = 0.85 factor. Non-perpend. radiation
- shading fraction: 0.75 assumed for PHPP if not given. % of glass shaded (10-50%) winter & summer
- glazing fraction: 25% or more depend. on size. % of glass to frame

n_{50} Air-tightness calculation

$$n_{50} = \frac{V_{50}}{V_{n50}}$$

- n_{50}: Air-tightness **1/h@50Pa ACH@50Pa**
- V_{50}: Flow rate through the fan **m3/h**
- V_{n50}: Net air volume **m3** (Sometimes marked as V)

Yearly Heating Degree Hours

$$G_T = \frac{h_{month} \times \Delta T\ (Ti - Te)}{k}$$

- G_T: (kKh)/a
- h_{month}: Total heating hours **Kh** (month days x hours)
- ΔT: Average temp difference in a given month btw indoor temp 20 and outdoor temperature **°K**.
- k: Divide by 1000

Need to work out all 12 months, add all the values and we get the total number of heating hours per year in that climate.

Internal heat Gains

From people and equipment. Single family house on average 3740 kWh/year

$$Q_I = H_t \times 0.024 \times q_i \times A_{TFA}$$

- Q_I: **kWh/a**
- H_t: Heating period days/yr
- 0.024: Unit conversion factor
- q_i = Default internal heat gains for building type provided by PHPP

Heat Demand Ventilation Infiltration losses

$$Q_{V\text{-}Infil} = V_{n50} \times e \times n_{50} \times C_{air} \times G_t$$

- $Q_{V\text{-}Infil}$: **kWh/a**. Energy impact of a leaky building
- Building element:
  - V_{n50}: Air tightness test volume as measured for PH. **m3**
  - e: Coefficient e **% or decimal** Average leakage rate of 7% = 0.07
  - n_{50}: Air-tightness test result **1/h@50Pa**
- Climate conditions:
  - C_{air}: Heat carrying capacity of air Wh/(m3K) Constant **0.33Wh/m3K)**
  - G_t: Yearly Heating Degree Hours. Values per location/tables. **(kKh)/a**

Window Heat Demand Energy Gains

Total for every window/ door in the building

$$Q_S = r \times \text{g-value} \times A_W \times G_{1\ or\ 2}$$

- Q_S: Solar heat gain **kWh/a**
- r: Solar reduction factor **Unitless**
- g-value: Solar Heat Gain Coefficient **Unitless**
- A_W: Window area **m2** Whole window incl frame
- $G_{1\ or\ 2}$: Average global radiation **kWh/m2a** Varies by climate and orientation

Annual Space Heating Demand Energy Balance Equation

Q_H = Quantity of energy needed to maintain 20 degrees C throughout the entire heating/cooling season (calculated for every month of the year) in a particular climate within a particular thermal envelope and per m2 of TFA.

$$Q_H = Q_T + Q_{T\text{-}TB} + Q_{V\text{-}Infil} + Q_{V\text{-}MVHR} - [\eta \times (Q_S + Q_I)]$$

Heating demand losses QL / Heating demand gains

See top left

- Q_H: Units **kWh/a**
- Q_T: Heating transmis. losses **kWh/a**
- $Q_{T\text{-}TB}$: Transmission losses minus thermal bridge losses **kWh/a**
- $Q_{V\text{-}Infil}$: Air Infiltration Ventilation losses **kWh/a**
- $Q_{V\text{-}MVHR}$: MVHR Ventilation losses **kWh/a**
- η: Eta = Utilisation/ Safety factor **Unitless** Provided by PHPP.
- Q_S: Solar heat gain **kWh/a**
- Q_I: Internal heat gains **kWh/a**. Default value is **1.6 W/m2**

$$Q_{H\ specific} = \frac{Q_H}{A_{TFA}}$$

$Q_{H\ specific}$ **kWh/(m2a)**; Q_H **kWh/(a)**; A_{TFA} **m2**

$Q_{H\ specific} \leq$ 15kWh/(m2a) PH

$Q_{H\ specific} \leq$ 25kWh/(m2a) EnerPHit

Heat Demand Planar Transmission losses (walls, roofs, windows, etc.)

$$Q_T = A \times U \times f_t \times G_t$$

- Q_T: kWh/a
- Building element:
  - A: Area of element measured on the outside. **m2**
  - U: U-value of element **W/(m2K)**
- Climate conditions:
  - f_t: Temperature Factor **(Unitless) Above ground = 1.0; Below varies.** Omitted for windows.
  - G_t: Heating Degree Hours. Values per location/ tables. **(kKh)/a**

Heat Demand Linear Thermal Bridging Transmission losses

$$Q_{T\text{-}TB} = L \times \psi \times G_t$$

- $Q_{T\text{-}TB}$: kWh/a
- Building element:
  - L: Linear thermal bridge length. **metres (m)**
  - ψ: Psi value of TB element **W/(mK)**
- Climate conditions:
  - G_t: Yearly Heating Degree Hours. Values per location/tables. **(kKh)/a**

When asked for **specific** heating demand, divide result by TFA.

+

Heat Demand Point Thermal Bridging Transmission losses

$$Q_{T\text{-}TB} = \# \times \chi \times G_t$$

- $Q_{T\text{-}TB}$: kWh/a
- Building element:
  - #: Number of point thermal bridges. **Unitless**
  - χ: Chi value of TB element **W/K**
- Climate conditions:
  - G_t: Yearly Heating Degree Hours. Values per location/tables. **(kKh)/a**

When asked for **specific** heating demand, divide result by TFA.

U-value: Construction build up

$$U = \frac{1}{R_T}$$

- U: U-value **W/m2K**
- R_T: Sum of all R values within Construction build up in m2K/W

U-Value = how much energy (W) moves coninuously through one m2 of surface area with a 1 degree temperature (K) difference between faces.

R-value: Construction build up

$$R_T = Rsi + R1 + R2 + R3\ (...) + Rse$$

- R_T: R-value **m2K/W**
- Rsi: R-value INternal Surface
- R1: R-value material 1
- R2: R-value material 2
- R3: R-value material 3
- Rse: R-value EXternal Surface

R-value: Single material

$$R = \frac{d}{\lambda}$$

- R: R-value **m2K/W**
- d: depth/thickness of material (m)
- λ: Lambda/Thermal Conductivity of material (W/mK)

U-value for windows calculation

$$U_W = \frac{(U_g \times A_g) + (U_f \times A_f) + (\psi_{sp} \times L_{sp}) + (\psi_{inst} \times L_{inst})}{A_{window}}$$

- U_W: U-value **W/m2K**
- U_g: Glass U-value **W/(m2K)**
- A_g: Glass Area **m2**
- U_f: Frame U-value **W/(m2K)**
- A_f: Frame Area **m2**
- ψ_{sp}: Psi value of spacer **W/(mK)**
- L_{sp}: Spacer length
- ψ_{inst}: Psi value of install **W/(mK)**
- L_{inst}: Install/ perimeter length
- A_{window}: Gross window Area **m2**

0.04 W/(mK) Psi install value can be used for small domestic projects if not known.

Data sources: Mosart Passive House course (November 2023)
Passive House Institute (December 2023)