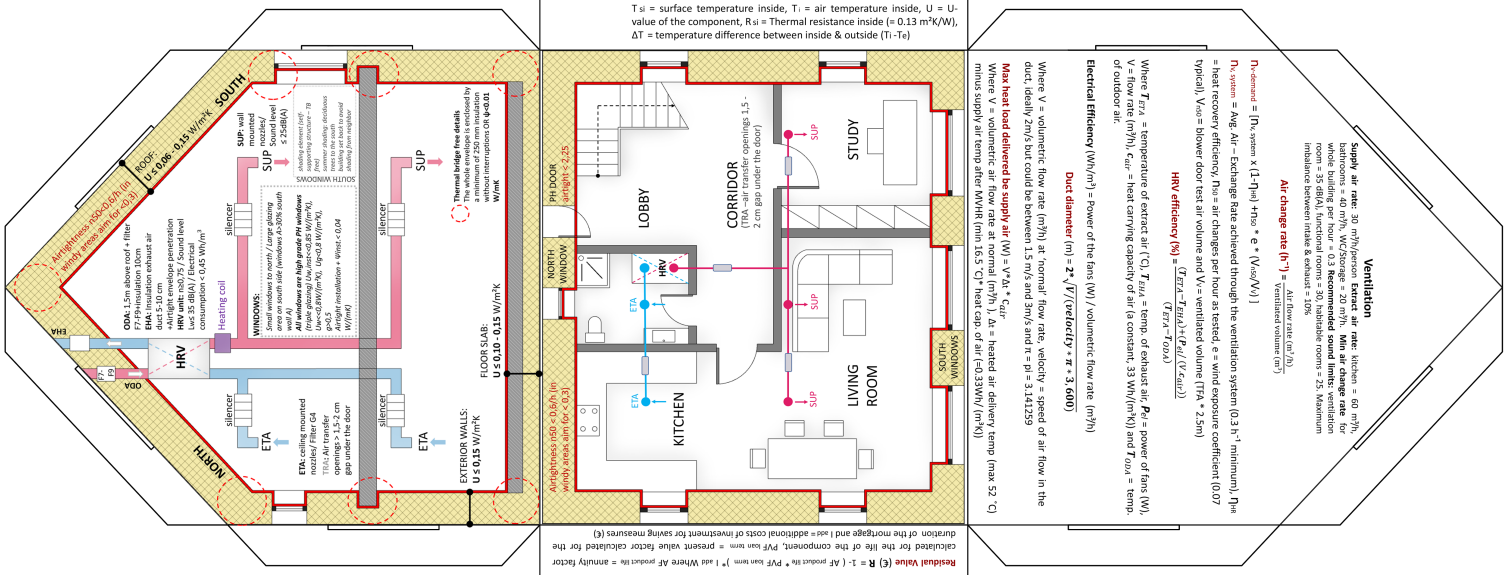
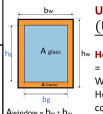


Windows

Solar reduction factor, r (unitless) = shading * dirt * reflection * glass %

U w-installed (W/m²K) =

$$\frac{(U_g * A_{glass}) + (U_f * A_{frame} + (\Psi_{spacer} * L_{glass}) + (\Psi_{install} * L_{installed})}{A_{window}}$$



$A_{window} = b_w * h_w$

$A_{glass} = b_g * h_g$

$A_{frame} = A_{win} - A_{glass}$

$L_{glass} = 2\,b_g + 2\,h_g$

$L_{install} = 2\,b_w + 2\,h_w$

Heat Demand Window Energy Balance (kWh/year)

$= Q_1 - Q_S = (A_w * U * G_1) - (r * g * A_w * G)$

Where A_W = glass window area, U = overall installed U –value, G_1 = Heating degree hours, r = reduction factor, g = solar heat gain coefficient, A_w = gross window area and G = annual global radiation

Heat Load Window Energy Balance (W)

$= P_T - P_S = (A_w * U * \Delta_T) - (r * g * A_w * \Delta G)$

Where A_W = glass window area, U = overall installed U –value, Δ_T = temperature difference in 2 weather conditions, r = reduction factor, g = solar heat gain coefficient, A_w = gross window area and ΔG = solar energy in 2 weather conditions

Surface Temperature of Component:

$T_{si} = T_i - (U * R_{si} * \Delta T)$

T_{si} = surface temperature inside, T_i = air temperature inside, U = U-value of the component, R_{si} = Thermal resistance inside (= 0.13 m²K/W), ΔT = temperature difference between inside & outside (T_i -Te)

Ventilation

Supply air rate: 30 m³/h/person **Extract air rate:** kitchen = 60 m³/h, bathrooms = 40 m³/h, WC/Storage = 20 m³/h. **Min air change rate** for whole building per hour = 0.3 **Recommended sound limits:** ventilation room = 35 dB(A), functional rooms = 30, habitable rooms = 25. Maximum imbalance between intake & exhaust = 10%

Air change rate (h^{-1}) = $\frac{\text{Air flow rate } (m^3/h)}{\text{Ventilated volume } (m^3)}$

$\Pi_{v\ demand} = [\Pi_{v\ system} \times (1-\eta_{HR}) + n_{SU} * e * (V_{SUP}/V_V)\ ]$

$\Pi_{v\ system}$ = Avg. Air – Exchange Rate achieved through the ventilation system (0.3 h^{-1} minimum), η_{HR} = heat recovery efficiency, n_{SU} = air changes per hour as tested, e = wind exposure coefficient (0.07 typical), V_{SUP} = blower door test air volume and V_V = ventilated volume (TFA * 2.5m)

HRV efficiency (%) $= \frac{(T_{EFA} - T_{ETA}) + (P_{air} / (\dot{V} * c_{air}))}{(T_{ETA} - T_{ODA})}$

Where T_{EFA} = temperature of extract air (°C), T_{SUP} = temp. of exhaust air, P_{air} = power of fans (W), $\dot{V}$ = flow rate (m^3/h), c_{air} = heat carrying capacity of air (a constant, 33 Wh/(m^3k)) and T_{ODA} = temp. of outdoor air.

Electrical Efficiency (Wh/m^3) = Power of the fans (W) / volumetric flow rate (m^3/h)

Duct diameter (m) $= 2 * \sqrt{\dot{V} / (velocity * \pi * 3.600)}$

Where $\dot{V}$ = volumetric flow rate (m^3/h) at 'normal' flow rate, velocity = speed of air flow in the duct, ideally 2m/s but could be between 1.5 m/s and 3m/s and π = pi = 3.141259

Max heat load delivered be supply air (W) = $\dot{V} * \Delta t * c_{air}$

Where $\dot{V}$ = volumetric air flow rate at normal (m^3/h), Δt = heated air delivery temp (max 52 °C) minus supply air temp after MVHR (min 16.5 °C)* heat cap. of air (=0.33Wh/(m^3K))

Heating load

Ventilation losses $P_V = \dot{V}_V * n_{v\text{-load}} * c_{air} * \Delta T$

Ventilated volume * Effective air change rate (load) * heat cap. of air (=0.33 Wh/(m^3K)) * temperature difference in 2 weather conditions

Transmission losses $P_T = A * U * f_i * \Delta T$

Area of thermal envelope * U-value * Temperature-correction factor (=1) * temperature difference in 2 weather conditions

Solar Gains $P_S = r * g * A_w * \Delta G$

Reduction factor * g-value * gross window area * global irradiation in 2 weather conditions

Internal heat gains $P_I = q_{i,p} * A_{TFA}$

Internal heat Gains (= 1.6 W/m^2, unoccupied) * Treated floor Area

Heating Demand

$Q_H = (Q_1 + Q_L) - \eta * (Q_I + Q_S)$

where η is a utilization factor

Ventilation losses $Q_V = \dot{V}_{v\text{-demand}} * C_{air} * G_1$

Ventilated volume * infiltration rate * Heat cap. of air (=0.33 Wh/(m^3K)) * Heating degree hours

Transmission losses $Q_T = A * U * f_i * G_1$

Area of thermal envelope * U-value * Temperature-correction factor * Heating degree hours

Solar gains $Q_S = r * g * A_w * G$

Reduction factor * g-value * gross window area * global irradiation

Internal heat gains $Q_I = t_{heat} * q_i * A_{TFA}$

Length heating period (no. of heating days per year * 0.024 kh/d) * internal heat gains q=2.1 W/m^2) * Treated Floor Area

Thermal Bridge Free:

Linear Thermal bridges (Psi-values) = Ψ (exterior demensions) < 0.01 W/mk

Point Thermal bridges (Chi-values) = ΔUTB = ΣχjA ≤ 0.01 W/ m²K

Q_I (kWh/year) = $L_\Psi * \Psi * f_I * G_1$

P_T (W) = $L_\Psi * \Psi * \Delta T$

Length * Linear thermal bridge Psi value * Temperature correction factor * Heating degree hours

Length * Linear Thermal bridge Psi value* Temperature difference

Economics

Present Value PV = $C * ((1-(1+i)^{-n}) / i)$

Where PV = present value of saving (additional borrowing capacity due to energy saving), C= savings in 1st year, i = real interest rate (written in decimal form, eg. 5% written as 0.05) and n= years over which present value is calculated (mortgage term)

PVF = present value factor = $((1-(1+i)^{-n})/i)$

Annuity A = $P * (i / (1-(1+i)^{-n}))$

Where A = Annuity (annual repayment amount), P = Principle amount borrowed, i = real interest rate (written in decimal form, eg. 5% written as 0.05) and n = years over which mortgage is repaid

AF = annuity factor = $(i / (1-(1+i)^{-n}))$

Interest Rate real = $((1 + \text{nominal}) / (1 + r)) - 1$

Where real is the 'real' interest rate on deposits which takes into account inflation, nominal = deposit rate quoted by bank and r = inflation rate (all rates written in decimal form as above)

Price of saved kWh $P_{saved} = ((AF_{loan\ term} * (i_{add} - R)) + Z) / E_{saved}$

Where $AF_{loan\ term}$ = annuity factor (based on loan term), i_{add} = additional costs of investment for saving measures (€), R = residual value of components (€), Z = possible annual additional costs (€), E_{saved} =annual energy saving (kWh)

Residual Value (€) $R = 1 - (AF_{product\ life} * PVF_{loan\ term})^* i_{add}$ Where AF $_{product\ life}$ = annuity factor calculated for the life of the component, $PVF_{loan\ term}$ = present value factor calculated for the mortgage and i_{add} = additional costs of investment for saving measures (€)

Passive House Certification Criteria

Heating energy demand: ≤ **15** kWh/(m²a) or Building heating load ≤ **10** W/m²

Cooling Demand ≤ **15** kWh/m²a + dehumidification contribution

Primary energy demand: ≤ **120** kWh/(m²a) or Renewable Primary Energy (PER) Demand ≤ **60** kWh/m²a

Building airtightness : ≤ **0.6** /h
Excess temperature frequency (25°C): ≤ 10%

Also: Ventilation with ≥ **75%** heat recovery
Electricity demand max. **0.45** Wh/m³

U-value (W/m²k)

$$U = \frac{1}{R_T} = \frac{1}{R_{si} + d_1/\lambda_1 + d_2/\lambda_2 + d_3/\lambda_3 + R_{se}}$$

Where d = thickness of each layer, in meters, and λ is the conductivity of materials in W/mK

Rsi Roof = 0.10 m²K/W, Walls= 0.13, Floors = 0.17

Rse Roof = 0.04 m²K/W, Walls= 0.04, Floors = 0.00

Heating Degree Hours kKh/

Example for January $G_{t\text{-January}} = (T_i - Te) * h_{Jan}$

$G_{t\text{-Jan}}$ = (20'-(0.8')) K * 31d *0.024 kh/d = 15.475 kKh

Airtightness

$n_{50} = \frac{V_{50}}{V_{air}} = \frac{\text{(mesured air flow rate in m}^3\text{/h)}}{\text{(net interior air volume in m}^3\text{)}}$

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