École Polytechnique
Year 2022-2023

Erik Johnson
Mathieu de Naurois
Daniel Suchet

PHY 555 – Energy and Environment

PC6 – Low consumption housing

Friday, November 18th 2022

In the context of reduced greenhouse gaz emission, housing occupies a dominant place; Indeed, more than a fifth of CO_2 emissions in the developed countries comes from domestic heating. The housing is, after industry, the second emitter of greenhouse gazes, and it represents about 30% of primary energy consumption. It is also a field where potential progress in terms of energy moderation are the most important. In this tutorial session we will study a simplified model of so-called *passive house*, for which consumption is largely reduced thanks to innovative architecture and the use of renewable energy sources.

Table 1 shows that the consumption of buildings has reduced considerably since the first oil shock. The purpose of a passive house is to further reduce this consumption by reducing losses and using natural inputs.

Consumption (kWh/m^2)	**1970**	**1988**	**Low consumption**
Envelope	130	50	10
Air renewal	50	30	15
Hot water	30	30	20
Household appliances, Hi-Fi, lighting ...	80	50	25
Total	290	160	70

Table 1 : Evolution of the average consumption of buildings. (Source Cythélia)

Important points in the realization of a passive house are:

- A high performance insulation, especially with a lack of thermal bridges.
- Airtightness, avoiding heat loss.
- A dual flow ventilation system (injecting fresh air and exhausting stale air out), made mandatory because the previous point, with head recovery heat and preheating of injected air.
- A contribution, even modest of external energy, favouring renewable energy sources.

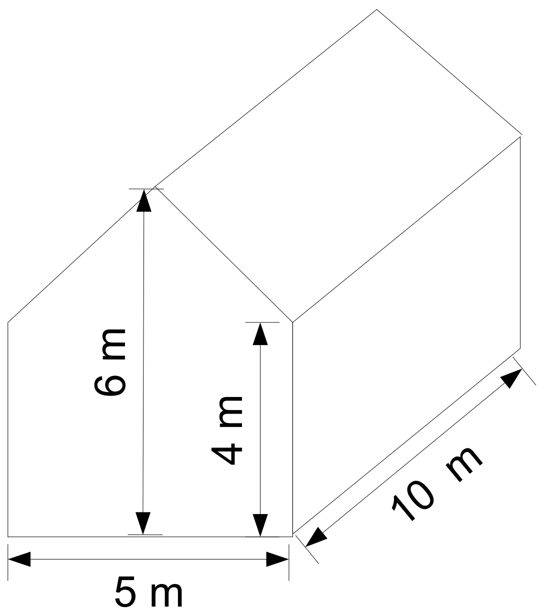

Figure 1 : Geometry of the house

1 – “Classical” house

Let's consider a house whose geometry (simplified) is given in Figure 1. This house is made cellular concrete, and has 130 m^2 of façade for 90 m^2 of roof. The living area (on two levels) is 100 m^2,for a total volume of 250 m^3.

Table 2 shows the thermal properties of various materials used in construction. Embodied energy (shown in the second column) is the amount of energy required for production, transportation, installation and recycling of materials or industrial products. In theory, a grey energy balance adds up energy expended in:

- the design of the product or service
- the extraction and transportation of raw materials
- the processing of raw materials and the manufacturing of the product
- the marketing of the product or service
- the use or the implementation of the product or the provision of service
- the recycling of the product

Material	**Thermal conductivity (W/K/m)**	**Embodied energy (kWh/m^3)**
Ordinary concrete	2,1	900
Cellular concrete	0,2	300
Hollow cellular concrete blocks 20 × 20 × 50 mm	1,15	410
Full brick	0,8	1 200
Hollow brick	0,4	675
Plasterboard BA13	0,25	1 450
Softwood	0,13	150
Wood particles panel	0,16	150
Insulating brick	0,11	
Straw	0,055	
Conventional insulation (glass wool, polystyrene ...)	0,04	Glass wool : 250 Rock wool : 150 Polystyrene : 450
High performance insulation (polyurethane foam)	0,025	1 000
Cellulose wool	0,04	6 to 10
Glass	~ 1 (from 0,8 to 1.2)	11 400
Immobile dray air	0,026	

Table 2 : Thermal conductivity and embodied energy of materials commonly used in construction. Various sources, including Passivhaus Institute Darmstadt and http://fr.ekopedia.org

1. Estimate, for an internal temperature of 20 °C and an outdoor temperature of 10 °C, the heat loss by thermal conduction through the walls. What would be the annual energy loss of the house by diffusion through the walls per unit area? Same question if the wall is covered with 4 cm of expanded polystyrene and plasterboard BA13 (13 mm thick). What is the grey energy involved in the insulation of walls? What is its energy payback time?
2. The walls are covered with 20 % of single pane windows of 5 mm thickness. What is the heat loss due to windows? Manufacturers give a surface transmittance of heat of $5{,}7\,\mathrm{W\,m^{-2}\,K^{-1}}$ for a single glass of 5 mm. Compare the resulting transmittance with the previously obtained result; where does the difference come from?
3. One generally considers the following distribution of heat losses
   - roof 30%
   - external walls 25%
   - air renewal 20%
   - windows and exterior doors 13%
   - floor 7%
   - thermal bridges 5%

   What is the total heat loss of the home? What would be the total annual energy consumption? (using simple assumptions about the annual temperature profile)

2 – Timber frame house

1. Let's now consider a “green” timber frame house with walls composed (from outside to inside) of
   - 8 cm softwood (maritime pine)
   - 10 cm cellulose wool injected under pressure
   - 4 cm wood particle panels

   Redo the calculation of heat losses. What embodied energy is involved in the construction of the walls?
2. Heat loss should not exceed, according to Minergie standards for low-energy houses, 42 kWh/m^2/year for the envelope (walls and roof). What cellulose wool thickness would be needed to achieve these standards? Then compare the embodied energy used to energy savings. What is the average time of return on investment?

3 – Double Flux Ventilation

1. In a classical house, not tight to air, the air renewal must be made to a rate close to 1 interior volume per hour. Estimate the heat loss by air renewal. (Dry air has a heat capacity $c_{\mathrm{air}}=1{,}007\,\mathrm{kJ/kg/K}$ and density $\mu_{\mathrm{air}}=1{,}2\,\mathrm{kg/m^3}$).
2. In a low-energy house, it is necessary to recover the heat from the exhaust air to preheat the incoming air. This can be done by means of a double-flux ventilation, combined with a high-efficiency heat exchanger (~ 80%). Assume that the outside air at 0 °C, and the stale air of the house at 21 °C, perform an energy balance of the ventilation system and determine the temperature of the air entering the house and the stale air outlet temperature.

4 – Provencal Well

The principle of Provencal wells (also called Canadian well) is to use the thermal inertia of the soil to preheat the incoming air in winter, and in contrast to cool it during summer (Figure 2).

The ground is modelled by a medium of density $\mu = 3000\,\mathrm{kg\,m^{-3}}$, specific heat capacity $c = 515\,\mathrm{J\,kg^{-1}\,K^{-1}}$ and thermal conductivity $\kappa = 1\,\mathrm{J\,m^{-1}\,s^{-1}\,K^{-1}}$ .The surface temperature fluctuates due to daily and annual variations. We model this variation by a sinusoidal variation $\theta(0,t) = \theta_0 - \theta_1 \cos\omega t$ with $\theta_0 = 10\,°\mathrm{C}$, $\theta_1 = 10\,°\mathrm{C}$ and $\omega/2\pi = 1$ year .

1. What is the magnitude of the temperature variation at a depth of 1 m? 2 m? How deep should the Provençal well be installed? What other device could exploit the temperature difference between the ground and the air?

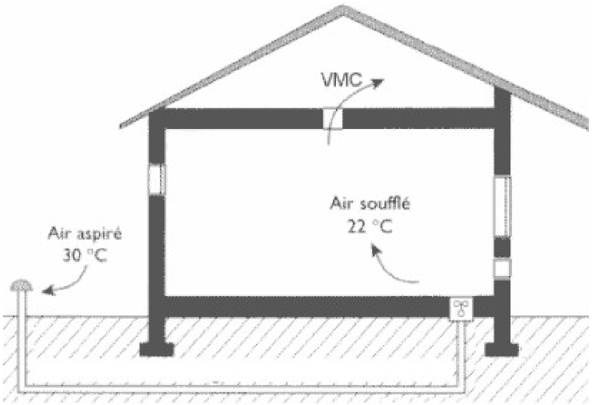

Figure 2 : Principle of operation of a Provencal well (during summer)