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Renewables in a changing climate – From nano to urban scale

LIFE CYCLE ASSESSMENT OF A POSITIVE ENERGY HOUSE IN FRANCE

Stéphane Thiers and Bruno Peuportier

Centre for Energy and Processes, MINES ParisTech

Introduction

- The « **positive energy house** »:
  A concept of high-performance residential house

- **Energy saving**
  - High insulation level
  - Air tightness
  - Heat recovery from extracted air
  - Efficient equipment

⇨ Low heating and electricity consumption

⇨ Can be achived applying the « *Passive House* » approach

- **Energy recovery from local renewable resources**
  - Solar radiation
  - Wind
  - Biomass (Wood, biogas)
  - Heat from the environment (air, ground, water)

Introduction

- One objective:

To achieve a positive *primary energy* balance for the building, on a yearly basis

Local balance approach: Considering local production as saved consumption

- Why building a PEH?:
  - Environmental and economical benefits
  - Recovery of energy from decentralized renewable resources

- **But a PEH needs more materials and more components**

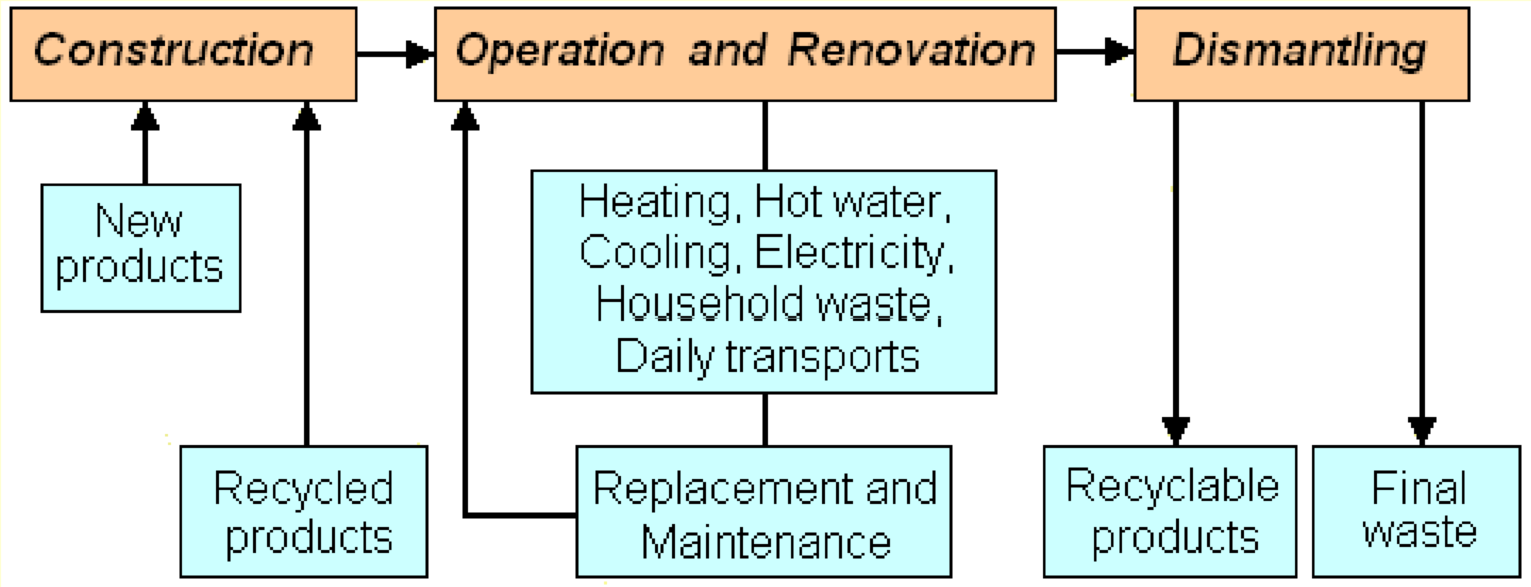
⇨ More embodied energy and increased environmental impacts at the construction

We need to check the environmental relevance of the PEH concept.

Life Cycle Assessment (LCA)

- LCA applied to a PEH to evaluate the environmental impacts

- Inventory of the energy and material flows (I/O) for each phase of the life cycle using databases (e.g. Ecoinvent)



- Evaluation of impact indicators (e.g. CML)

Method

1. Evaluation of the energy assessment, using a thermal dynamic simulation tool: COMFIE
   - Multizone simulator developed by CEP at MINES ParisTech
   - One year simulation
   - ➢ Heating load
   - ➢ Temperature in each zone, for thermal comfort evaluation

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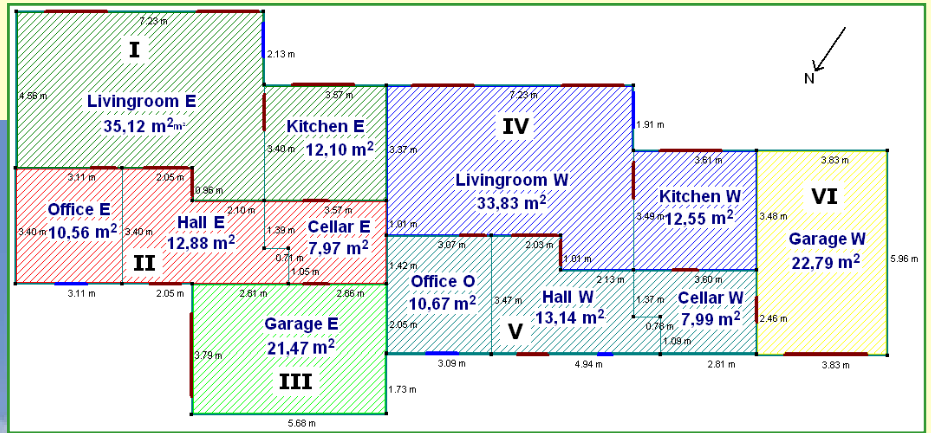
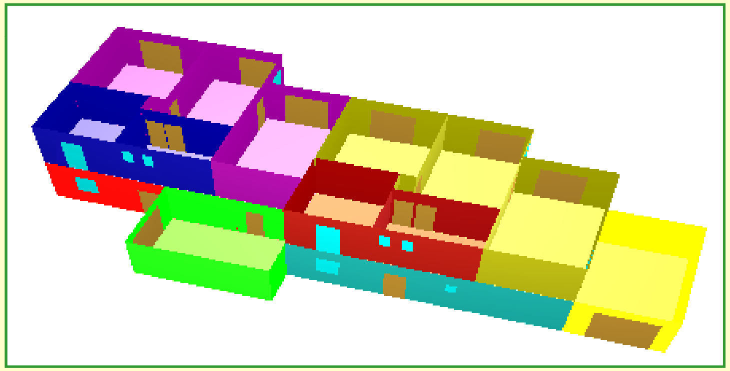
2. Evaluation of the LCA, using a specific tool: EQUER
   - Building LCA software developed by CEP at MINES ParisTech
   - Calculation of 12 impact indicators:

Impact indicator	Unit	Legend
Cumulative Energy Demand	GJ	ENERGY
Water consumption	m^3	WATER
Abiotic Depletion Potential	kg Sb-eq	RESOURCE
Non-radioactive waste creation	t eq	WASTE
Radioactive waste creation	dm^3	RADWASTE
Global Warming Potential at 100 years (GWP_{100})	t CO_2-eq	GWP_{100}
Acidification Potential	kg SO_2-eq	ACIDIF.
Eutrophication Potential	kg PO_4^{3-}-eq	EUTROPH.
Damage caused by the ecotoxic emissions to ecosystems	PDF.m^2.yr	ECOTOX
Damage to human health	DALY	HUMHEALTH
Photochemical Oxidant Formation Potential (Smog)	kg C_2H_4-eq	O_3-SMOG
Odour	Mm^3	ODOUR

Description of the building

- Two attached houses in North of France
  - Two-storied
  - 132 m² inhabitable area





Description of the building

- **« Passive house » label** (PHI)
- **Timber frame structure**
- **High insulation**
  - **external walls** (22 cm Cellulose, 15 cm Polystyrene)
  - **slab** (20 cm Polystyrene)
  - **attic** (40 cm cellulose)
  - **doors** (U= 0.78 $W.m^{-2}.K^{-1}$)
  - **Triple-glazed windows** (U_w= 0.71 W $W.m^{-2}.K^{-1}$)
- **Air-tightness** (0,58 ach at 50 Pa)
- **Solar protection** (external venetian blinds)

- **Earth-to-air heat exchanger** (length 2 x 30 m)
- **Heat Recovery Ventilation** (efficiency 70%)
- **Electric compact heat pump** (COP 3)
- **Thermal solar panels** (2 x 5 m^2)

Simulations

- Passive houses « virtually improved » by addition of Si polycristaline PV panels on the roof (76.6 m^2)

- 3 different heating solutions:

  1. **Compact electric heat pump** (COP 3) (*HP*)
  2. **Wood pellet condensing boiler** (HHV mean efficiency: 75 %) (*CB*)
  3. **Wood pellet Stirling engine micro-cogeneration unit** (*CHP*)

  Micro-CHP unit based on the

  « Sunmachine Pellet » unit ⟶

  previously characterized on a test bench and modeled at MINES ParisTech

- One year simulation (weather: Paris region = oceanic climate)

Results

- Computed energy loads of both houses
  (independent from the heating device)

Energy	Use	kWh/yr	kWh/m²/yr	
Heat	Heating	2032	7.7	17.7%
	Domestic Hot Water production	5255	19.9	45.9%
Electricity	Cooking, Lighting, other appliances	2354	8.9	20.6%
	Ventilation	1807	6.8	15.8%
Total		*11 448*	*43.4*	*100%*

- Very low heating load
- DHW production represents half the whole building load
- Thermal comfort is satisfactory most of the time

Results

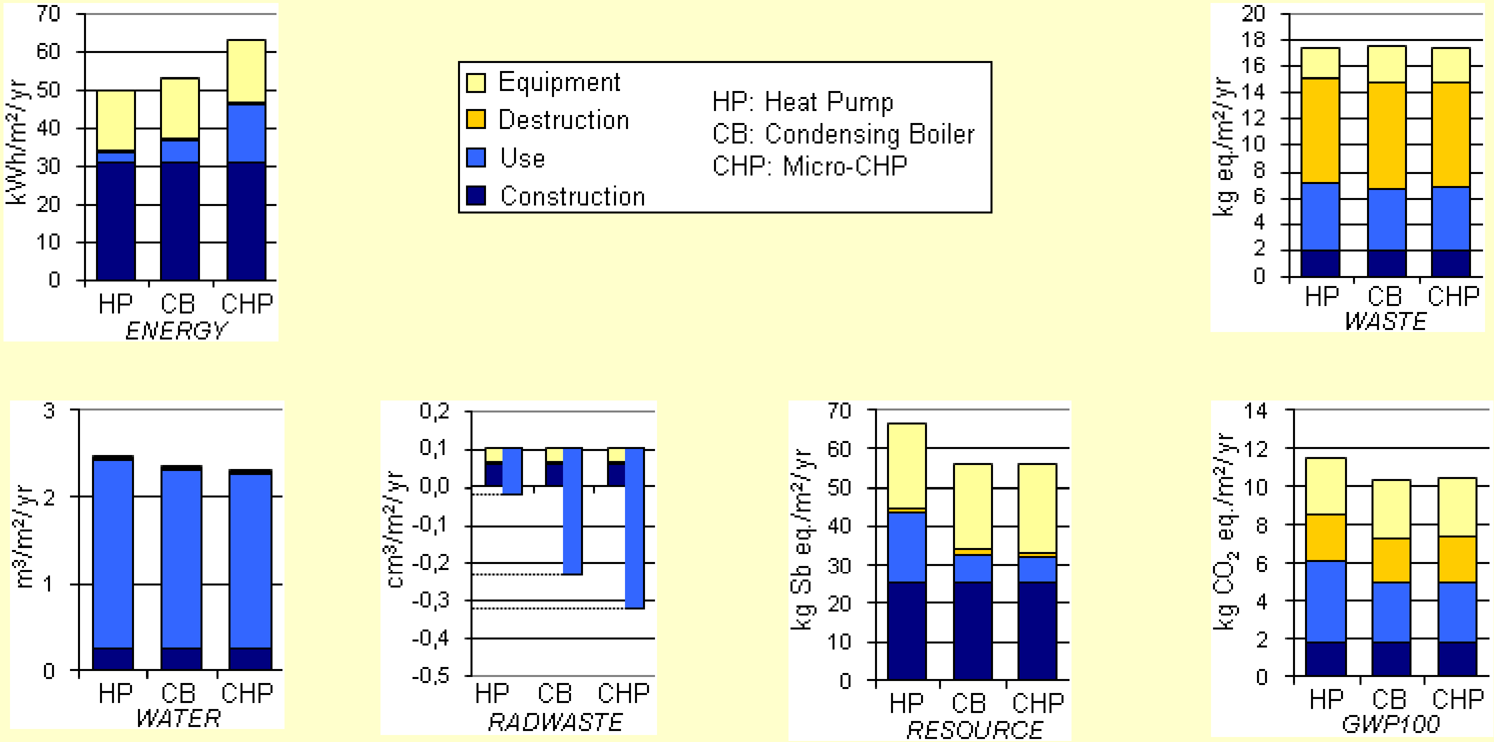
- Consumption and supply of both houses

Heating device	Consumption *kWh/yr*			Supply *kWh/yr*	*kWh_{PE}/yr*
	Wood pellets	**Electricity** *heating*	**Electricity** *base*	**Electricity** *base*	**Net Primary Energy Production**
HP	0	677	4837	6418	**+2805**
CB	5413	0	4161	6418	**+1160**
CHP	9228	0	4870	7586	**-1644**
PE ratios kWh_{PE}/kWh	*1.12*	*3.33*	*3.2*	*3.2*	

- PEH for both HP and CB solutions
- Limited performance of the CHP

Results

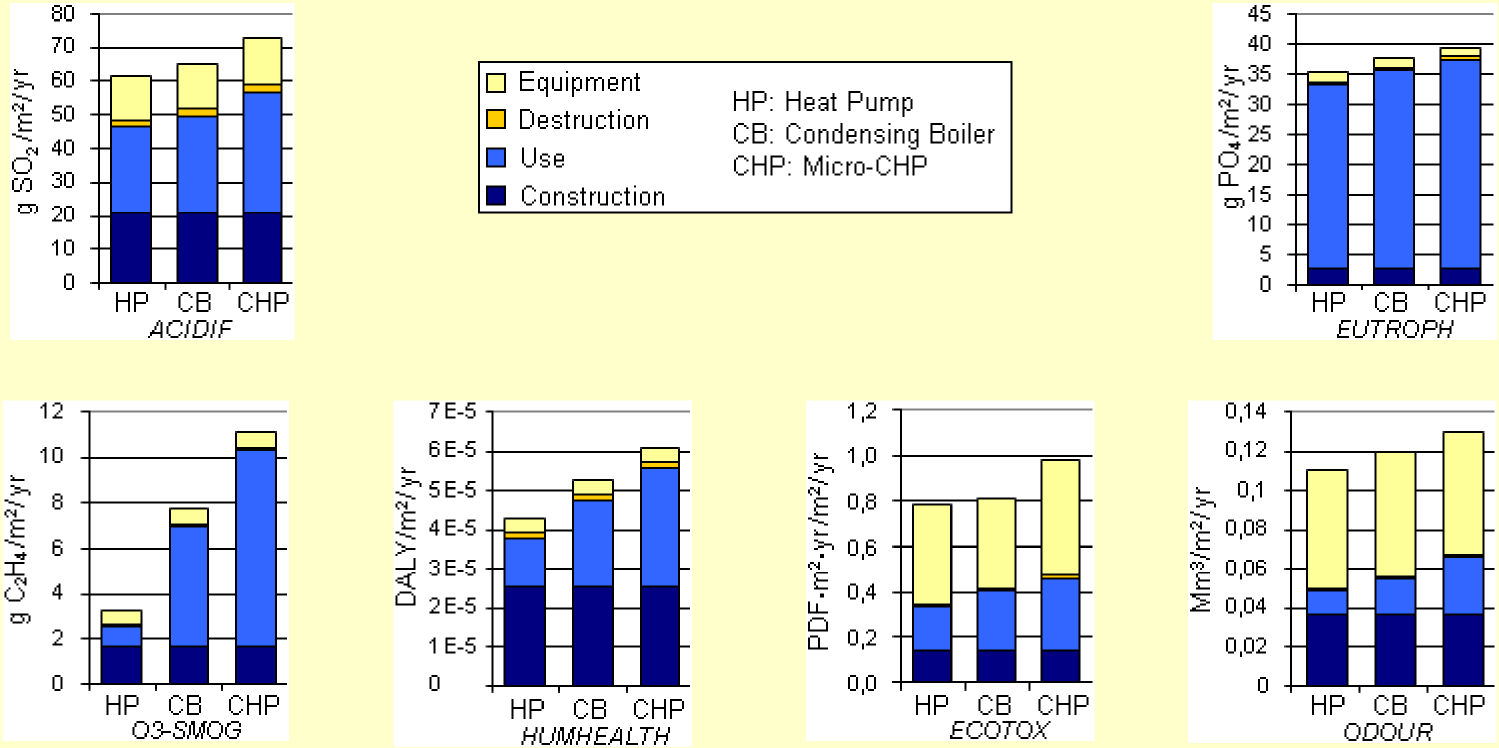
- LCA hypothesis
  - Lifetime of the building: 80 years
  - Household waste treatment and home-work transportation are not accounted for
- Results



4 indicators increased by electricity consumption

Results

Indicators increased by wood consumption



Discussion

- **Here, PEH with high performance**
  - e.g. low GWP_{100} : 11 kg $CO_2/m^2/yr$
- **Environmental impacts remain positive during the operation phase due to:**
  - Water consumption (water purification, sewage treatment)
  - Wood consumption (combustion)
  - Electricity consumption (generation)
- **Important contribution due to the equipment for some indicators**
  - Production process may be improved
  - Recycling may be implemented
  - High contribution of the PV panels

Conclusions

- A PEH has been studied using energy and life cycle assessment
- Strong influence of the heating device on some indicators
- **None of the three solutions seems optimal** but:
  - **PEH contributes to the reduction of radioactive waste production**, especially when not equipped with a heat pump
  - Condensing boiler and CHP reduce some impacts (e.g. contribution to greenhouse effect) but wood combustion reinforces air and water chemical pollution
  - The improvement of the efficiency of the micro-CHP unit could reduce these negative impacts.

Thank you for your attention