



COSTS AND LIFE-CYCLE ENERGY OPTIMIZATION FOR A LOW ENERGY HOUSING RENOVATION ACTIONS

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Introduction

Context :

■ **23/01/08** : European commission adopts the "climate plan" :

➔ **20%** reduction in emissions of greenhouse gases

➔ **20%** reduction in energy consumption

➔ **20%** renewables in the energy mix by 2020



■ **E4R Project ("Energy for renovation"):**

European project funded by the European Commission, partners in France, Spain and Portugal

Aim : to encourage and promote the retrofit of existing buildings

Through : realization of practical tools for energy evaluation and economics estimation

<http://www.e4rproject.eu/index.php?lang=fr>

Objective of this work:

optimizing the selection of renovation actions in a given housing relative to environmental and economic criteria.

Introduction

Problematic :

- ☑ Is a thorough energetic renovation interesting from a financial point of view ?
- ☑ What is the effort's level to achieve a low-energy-consumption?
- ☑ What is the environmental impact generated (or avoided) by renovation?
- ☑ Is it possible to reach a good compromise between economic and environmental aspects ?



Retrofit actions identification

■ In order to achieve energetic efficiency in buildings, European regulations stipulate the minimum requirements, well-insulation (U-values) and heat recovery.

■ A few retrofit actions and options are selected as following:

◆ **Interior Thermal Insulation (ITI) with three options:**

Extruded polystyrene (XPS), $\rho = 30$ [kg/m³] , $\lambda = 0.036$ W / mK

Polyurethane (PUR / PIR), $\rho = 30$ [kg/m³] , $\lambda = 0.032$ W / mK

Cellular glass, $\rho = 110$ [kg/m³], $\lambda = 0.045$ W / mK

◆ **Attic Thermal Insulation (ATI) with three options :**

Stone wool, $\rho = 30$ [kg/m³], $e = 0.3$ m, $\lambda = 0.04$ W / mK

Glass wool, $\rho = 22$ [kg/m³], $e = 0.3$ m, $\lambda = 0.04$ W / mK

Cellulose panel, $\rho = 70$ [kg/m³], $e = 0.3$ m, $\lambda = 0.04$ W / mK

◆ **Double or triple glazing windows, with typical joineries: PVC (*polyvinyl chloride*), Wood and Aluminum.**

Retrofit actions characterization

Approach: Life Cycle Analysis

Economic cost :

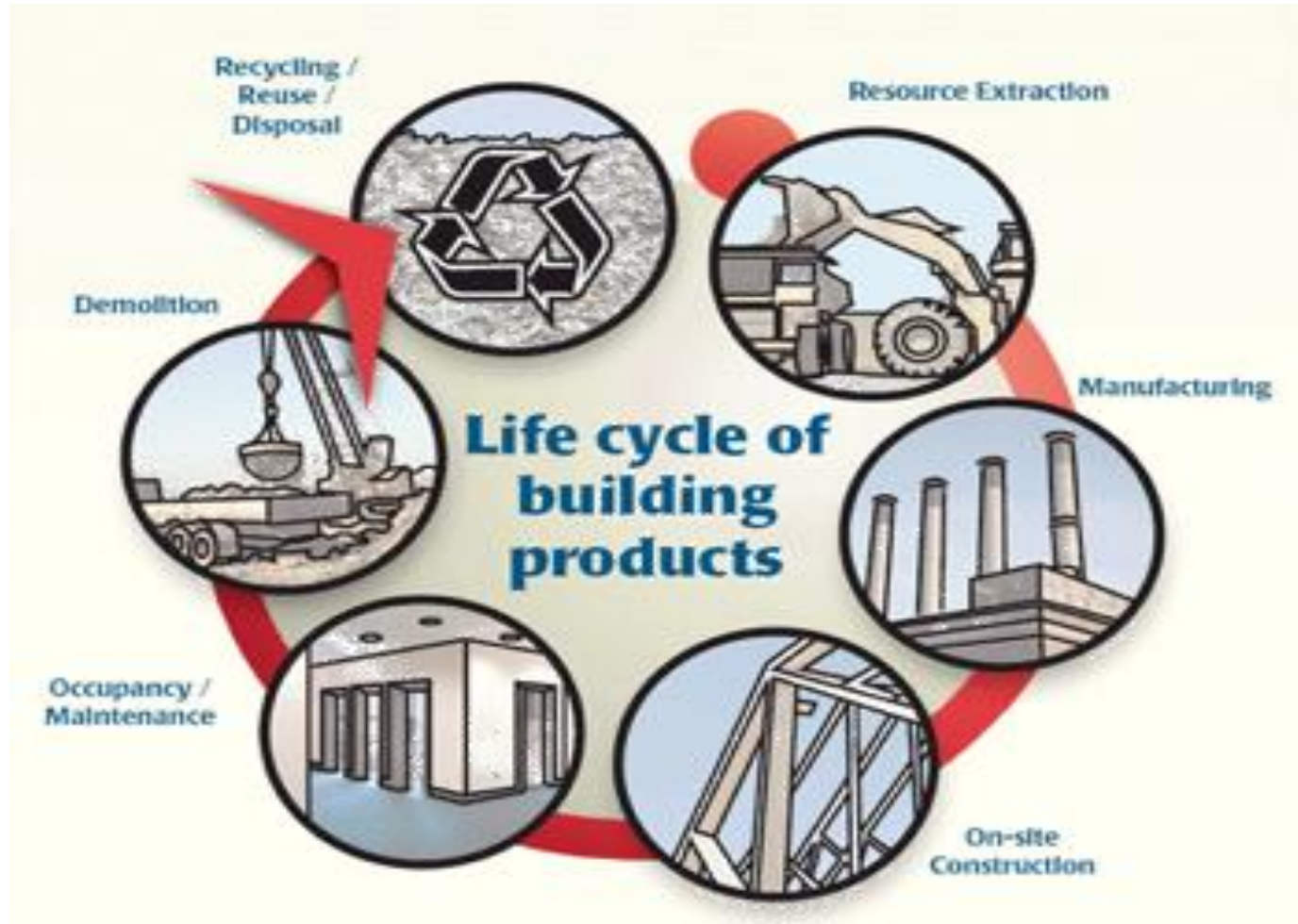
Life Cycle Cost : $LCC = C_a + C_{inst} + C_{maint} + C_r$

- **Acquisition cost : C_a**
- **Installation cost C_{inst} :** which includes the cost of removal
- **Replacement cost C_r :** in the specific case where elements of equipment must be replaced during its spanlife
- **Cumulative maintenance cost C_{maint} :**
The annual maintenance cost C_{maint} is calculated on the basis of a subscription to an annual maintenance contract.
 - « Present value factor » depends on the real interest rate (market rate and inflation rate) and the year.

Retrofit actions characterization

Approach: Life Cycle Analysis

Ecological cost: Estimated embodied energy



Retrofit actions characterization

Tab. 1 Retrofit actions characteristics

Renovation action	Cost (€/m ²)	Embodied Energy (Kwh/m ²)	
		Fabrication	Elimination
ITI : Extruded polystyrene (XPS), $\rho= 30$ [kg/m ³] , $e= 0.2$ m, $\lambda = 0.036$ W / mK, $U=0.17$ W/m ² K	67.2	192.2	1.4
ITI : Polyurethane (PUR / PIR), $\rho = 30$ [kg/m ³], $e=0.2$ m, $\lambda =0.032$ W / mK, $U= 0.15$ W/m ² K	74.6	193.5	3.2
ITI : Cellular glass, $\rho=110$ [kg/m ³], $e= 0.15$ m, $\lambda= 0.045$ W / mK, $U= 0.28$ W/m ² K	74.8	115.2	2.1
ATI : Stone wool, $\rho= 30$ [kg/m ³], $e=0.3$ m, $\lambda = 0.04$ W / mK, $U= 0.16$ W/m ² K	46.5	127.8	2.5
ATI : Cellulose panel, $\rho= 30$ [kg/m ³], $e=0.3$ m, $\lambda = 0.04$ W / mK, $U= 0.16$ W/m ² K	92.4	132.1	3.6
PVC windows with double glazing , $U_w = 1.36$ W/m ² K	750	493.5	48.8
Wood windows with double glazing, $U_w= 1.33$ W/m ² K	850	258.4	3.3
Aluminum windows with double glazing, $U_w= 1.44$ W/m ² K	500	606.7	1.3
Wood windows with triple glazing, $U_w= 0.96$ W/m ² K	986	347	3.9

Methodology description

Proposed method is based on dynamic thermal simulation with HAMLab which is basically a collection of tools for MatLab/Simulink. In order to find the best solution in terms of costs and energy, simulation is automatically repeated many times with different values of design parameters.

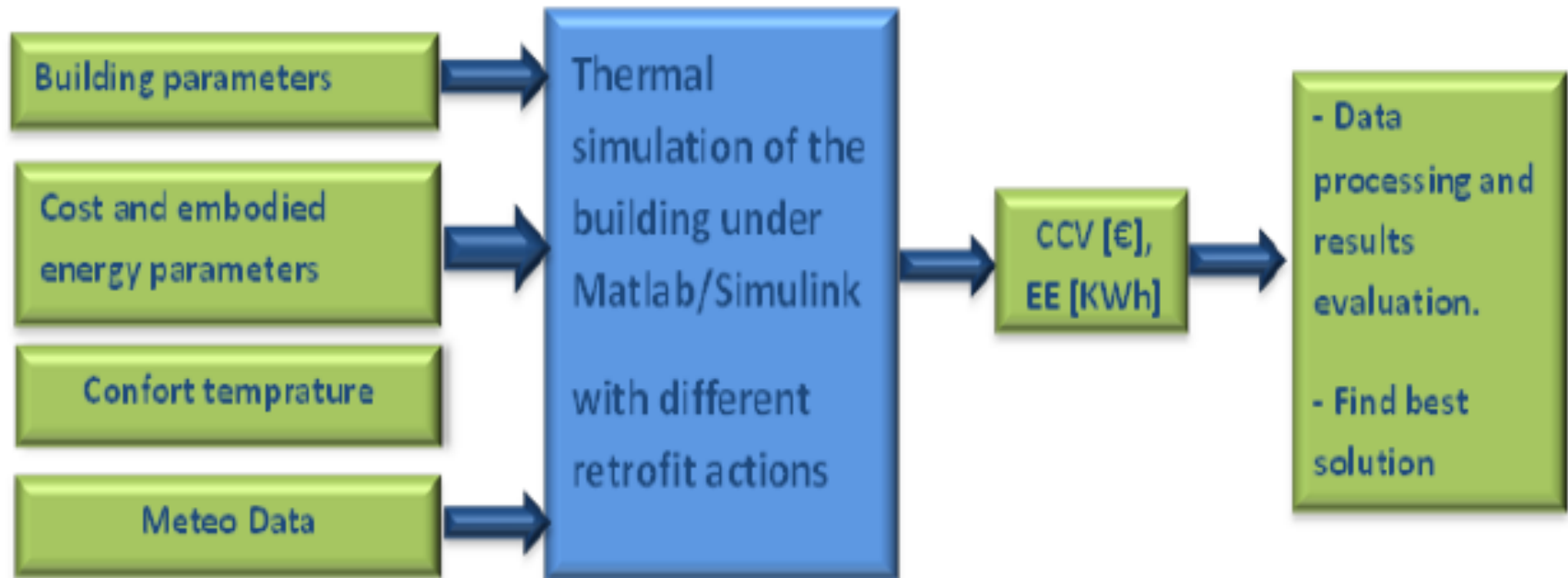


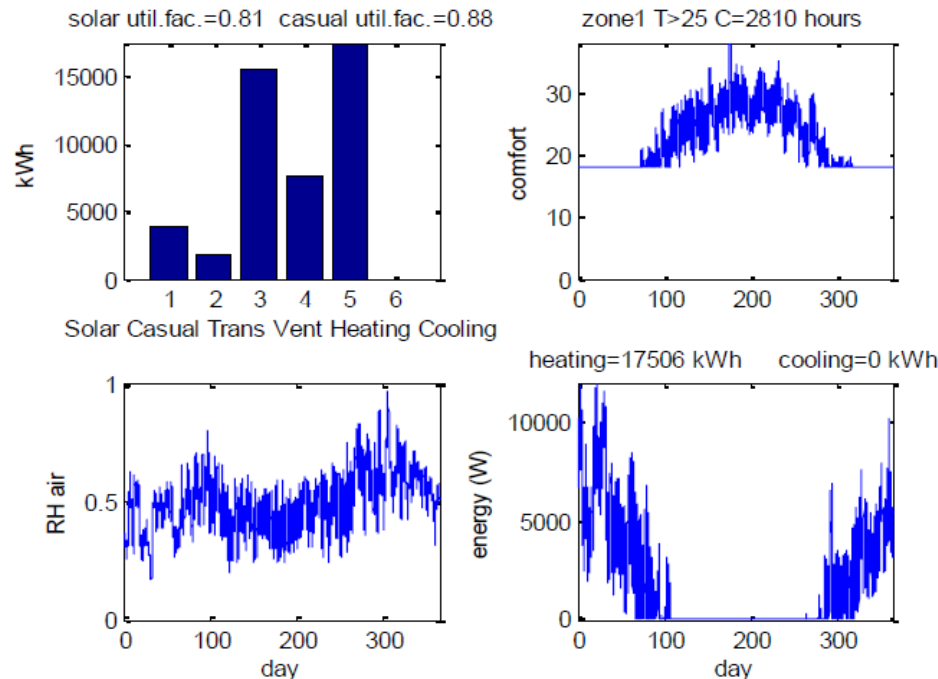
Fig. 1 Flowchart of proposed method

Case study and results

Building description and dynamic thermal simulation

A house in Bordeaux has been selected for application. It dates from the beginning of the last century and is located in the city center. Only its west and south walls are exterior. Its main characteristics are:

- Total surface : $S_{tot} = 140 \text{ m}^2$ (without considering basement)
- Surface of exterior walls : $S_{ext} = 152.4 \text{ m}^2$
- Glass surface : $S_{glass} = 18.72 \text{ m}^2$
- Surface of outside doors : $S_{doors} = 5.5 \text{ m}^2$
- Ceiling height : $h_s = 3 \text{ m}$



Results for dynamic thermal simulation (*Fig.2*) with meteorological data of 2011 give 17506 kWh/year of energy consumption for heating (close to invoice 17216 kWh / year).

Fig. 2 Results of dynamic thermal simulation of the existing house (Before renovation actions)

Case study and results

Parametric study and optimization results

Our methodology compares global costs and life cycle energies of retrofitting actions for different combinations in the discrete domain. Results are shown below:

- ***Solution (1)*** with the lowest investment in terms of costs and Life cycle embodied energy of actions :

ITI material	ITI thik[m]	ATI material	ATI thik [m]	Wind. Frame	Galaz. Type	Econs [Kwh/yr]	LCC[Euro]	EE[KWh]	Remb_EE [year]	Remb_LCC[Year]
Polystyrene	NAR*	Stone wool	0,3	NAR	NAR	15641,73389	9538,20	8852,20	5,12	90,89

*NAR: No Action Recommended

- ***Solution (2)*** the best in terms of heating energy saving :

ITI material	ITI thik[m]	ATI material	ATI thik [m]	Wind. Frame	Galaz. Type	Econs [Kwh/yr]	LCC[Euro]	EE[KWh]	Remb_EE [year]	Remb_LCC[Year]
Polyurethane	0,2	Glass wool	0,3	wood	Triple	6350,81	42655,36	27682,68	3,82	67,92

- ***Solution (3)*** with the best compromise between the principle criteria: economic and actions embodied energy payback time in addition to heating energy saving

ITI material	ITI thik[m]	ATI material	ATI thik [m]	Wind. Frame	Galaz. Type	Econs [Kwh/yr]	LCC[Euro]	EE[KWh]	Remb_EE [year]	Remb_LCC[Year]
Cellular glass	0,1	Stone wool	0,3	wood	Double	7464,37	22692,60	24172,20	2,26	40,14

Case study and results

Parametric study and optimization results

Results show that:

- A thorough energetic renovation (**solution (2)**) is not interesting from a financial point of view. A triple glazing is not enough benefit from both financial and energetic.
- It is not necessary to conduct a thorough renovation of housing. A careful insulation of the roof (**solution 1**) and / or average insulation of exterior walls (**solution 3**) are sufficient.
- With multitude solutions obtained, designers can choose according to economic and/or environmental considerations. For example, **solution (3)** guarantees a good tradeoff between the principle criteria: economic and actions embodied energy payback time in addition to heating energy saving. This one gives the lowest payback times.

Conclusion

➤ In this paper, an approach for the optimization of both economic and environmental costs of buildings rehabilitation is proposed.

➤ Economic and environmental costs (especially in term of embodied energy) of each renovation actions have been collected and evaluated.

➤ Then retrofit actions have been recommended according to economic and energetic criteria.

➤ Retained solutions shows that thorough energetic renovation is not always a good choice.

➤ A parametric study with an optimization aim before design is thus primordial.

Perspectives

Using EnergyPlus and an optimization algorithm

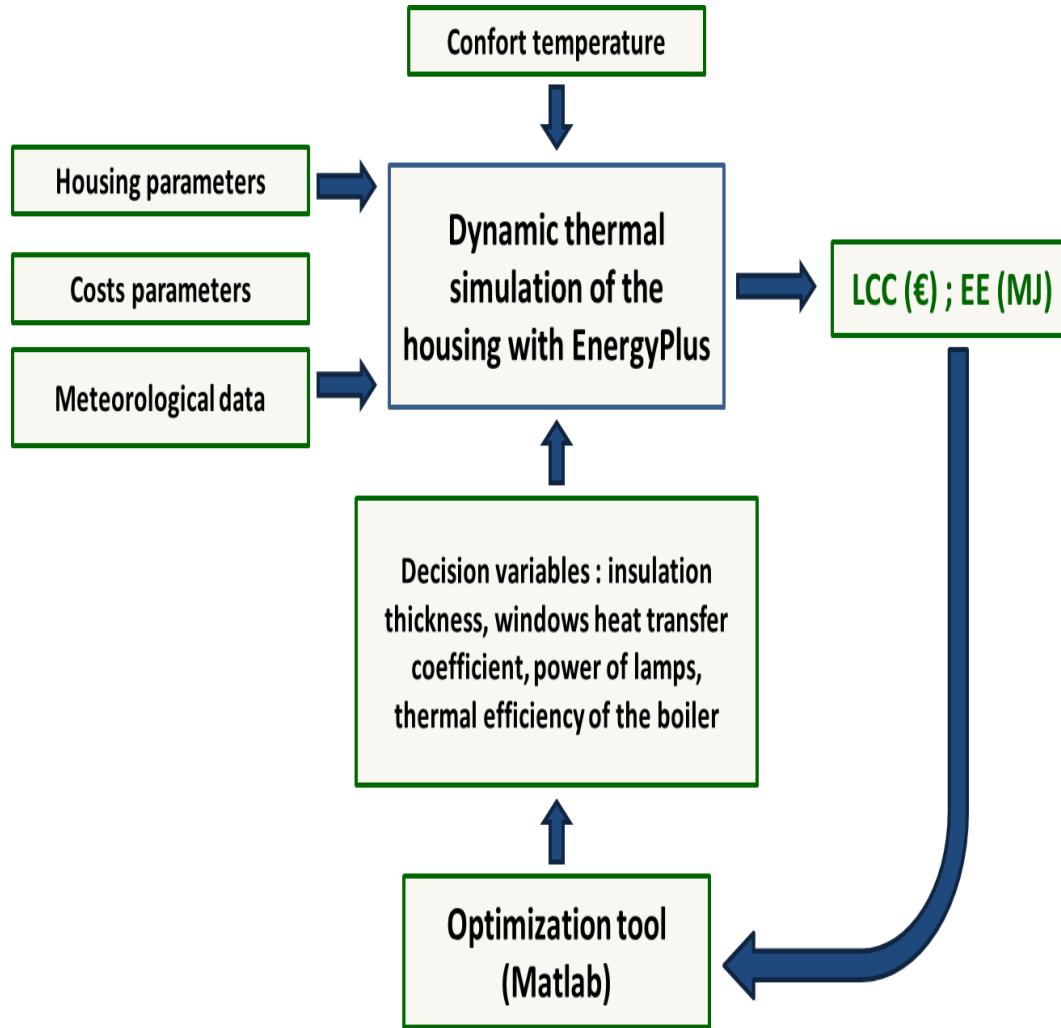


Fig. 3 : Simulation-optimization methodology

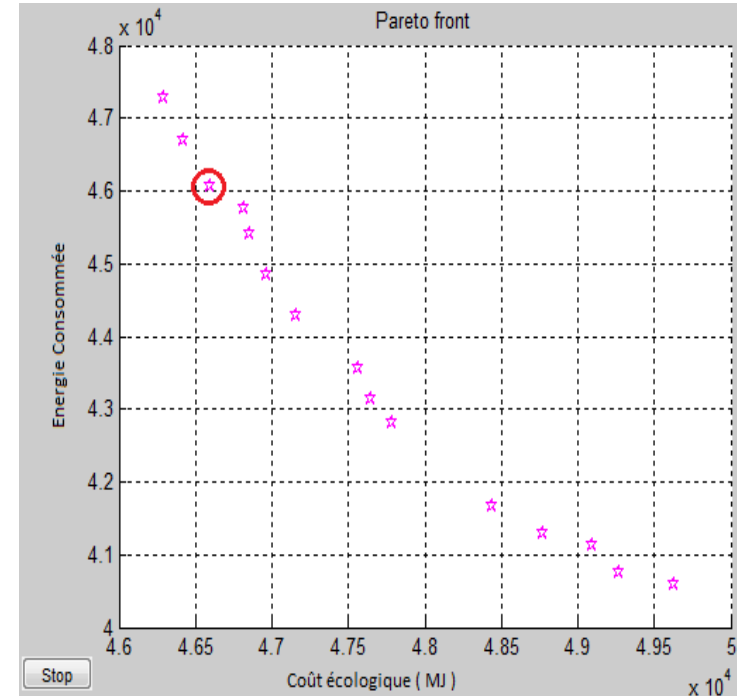


Fig. 4 : Example of a Pareto front when varying interior walls insulation thickness of a house

Thank you for
your attention!