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

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Summary

Economic cost is a very important decision criterion in renovation projects. Environmental impacts are also gaining more. Renovation's actions will improve energy efficiency in building but also concerns manufacturing, transportation, emissions,…
In this paper, an approach for optimizing both economic and environmental costs is presented. A procedure of actions optimization based on thermal dynamic simulation has been successfully applied for a house in France. Different scenarios are studied and analyzed.

Keywords: Buildings, Retrofits, Costs, Life-Cycle Energy, Optimization

1 Introduction

Improving energy efficiency in existing buildings is a major challenge to achieve the 20% reduction of energy consumption in the European Union by 2020 [1].
In addition to comfort and esthetics, renovation projects are limited by budget, and measures must be efficient. Another aspect gaining more and more interest is the environmental impact of actions [2] [3].
More generally, a few questions remain:

- 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?

Thus, the paper is organized as follows. Second section is dedicated to retrofit actions identification and characterization. Section 3 describes the methodology. Next, in section 4, results are presented and discussed.

2 Retrofit actions identification and characterization

2.1 Retrofit actions identification

In order to achieve energetic efficiency in buildings, European regulations stipulate the minimum requirements, well-insulation (U-values) and heat recovery [4]. Our study is focused on improving thermal insulation of the building (external walls, roof, floor and windows), reducing heat losses through the building's envelope. A few retrofit actions and options are selected as following:

- Interior Thermal Insulation (ITI) with three options:
  - Extruded polystyrene (XPS), ρ = 30 [kg/m3] , λ =0036 W / mK
  - Polyurethane (PUR / PIR), ρ = 30 [kg/m3] , λ =0.032 W / mK
  - Cellular glass, ρ =110 [kg/m3], λ= 0045 W / mK
- Attic Thermal Insulation (ATI) with three options :
  - Stone wool, ρ= 30 [kg/m3], e=0.3 m, λ = 0.04 W / mK
  - Glass wool, ρ = 22 [kg/m3], e= 0.3m, λ= 0.04 W / mK
  - Cellulose panel, ρ=70[kg/m3], e=0.3 m, λ=0.04 W / mK
- Double or triple glazing windows, with typical joineries: PVC (*polyvinyl chloride)*, Wood and Aluminum.

2.2 Retrofit actions characterization

This study is focusing on costs and life cycle energy minimization in buildings renovation. So, retrofit actions are characterized according to these criteria.
Acquisition and installation costs have been evaluated with several quotes [5, 6] and include old equipment removal. Maintenance and replacement costs are not considered (because themselves can be accounted as renovation actions).
About Life Cycle Energy, for each action, embodied energy (sum total of energy use from cradle to grave of a product) has been assessed with various catalogs from Swiss Federal Office of Energy (FOE) and eco-bau association [7]. Lifespan period of 30 years is considered. Transportation from manufacturing plant and on site treatment are not included: it is not easy to evaluate them accurately.
Retrofit actions characterizations with different economic and energetic assessments are summarized in the following table:

Tab. 1 *Retrofit actions characteristics*

Renovation action	**Cost (€/m²)**	**Embodied Energy (Kwh/m²)**	
		Fabrication	**Elimination**
ITI : Extruded polystyrene (XPS), ρ= 30 [kg/m3] , **e= 0.1 m**, λ = 0.036 W / mK, U= 0.33 W/m²K	56	108.8	1.2
ITI : Extruded polystyrene (XPS), ρ= 30 [kg/m3] , **e= 0.15 m**, λ = 0.036 W / mK, U= 0.23 W/m²K	61.6	150.5	1.3
ITI : Extruded polystyrene (XPS), ρ= 30 [kg/m3] , **e= 0.2 m**, λ = 0.036 W / mK, U=0.17 W/m²K	67.2	192.2	1.4
ITI : Polyurethane (PUR / PIR), ρ = 30 [kg/m3],**e=0.1 m**, λ =0.032 W / mK, U=0.3 W/m²K	62.2	109.5	2
ITI : Polyurethane (PUR / PIR), ρ = 30 [kg/m3],**e=0.15 m**, λ =0.032 W / mK, U=0.2 W/m²K	68.5	151.5	2.6

Renovation action	Cost (€/m²)	Embodied Energy (Kwh/m²)	
		Fabrication	**Elimination**
ITI : Polyurethane (PUR / PIR), ρ = 30 [kg/m3],**e=0.2 m**, λ =0.032 W / mK, U= 0.15 W/m²K	74.6	193.5	3.2
ITI : Cellular glass, ρ=110 [kg/m3], **e= 0.1 m**, λ = 0.045 W / mK, U= 0.41 W/m²K	64.8	85.3	1.7
ITI : Cellular glass, ρ=110 [kg/m3], **e= 0.15 m**, λ= 0.045 W / mK, U= 0.28 W/m²K	74.8	115.2	2.1
ITI : Cellular glass, ρ=110 [kg/m3], **e= 0.2 m**, λ=0.045 W / mK, U=0.21 W/m²K	84.8	145.1	2.5
ATI : Stone wool, ρ= 30 [kg/m3], **e=0.3 m**, λ = 0.04 W / mK, U= 0.16 W/m²K	46.5	127.8	2.5
ATI : Glass wool, ρ= 30 [kg/m3], **e=0.3 m**, λ = 0.04 W / mK, U= 0.16W/m²K	47.4	174.3	2.4
ATI : Cellulose panel, ρ= 30 [kg/m3], **e=0.3 m**, λ = 0.04 W / mK, U= 0.16 W/m²K	92.4	132.1	3.6
PVC windows with double glazing , Uw = 1.36W/m²K	750	493.5	48.8
Wood windows with double glazing, Uw= 1.33W/m²K	850	258.4	3.3
Aluminum windows with double glazing, Uw= 1.44 W/m²K	500	606.7	1.3
PVC windows with triple glazing, Uw=0.99 W/m²K	870	582.2	49.4
Wood windows with triple glazing, Uw= 0.96 W/m²K	986	347	3.9
Aluminum windows with triple glazing, Uw= 1.06 W/m²K	580	695.3	1.9

3 Methodology description

Proposed method is based on dynamic thermal simulation with HAMLab which is basically a collection of tools for MatLab/Simulink [8]. 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. Data are processed and solutions are deduced. Following chart depicts the principle of the proposed method:

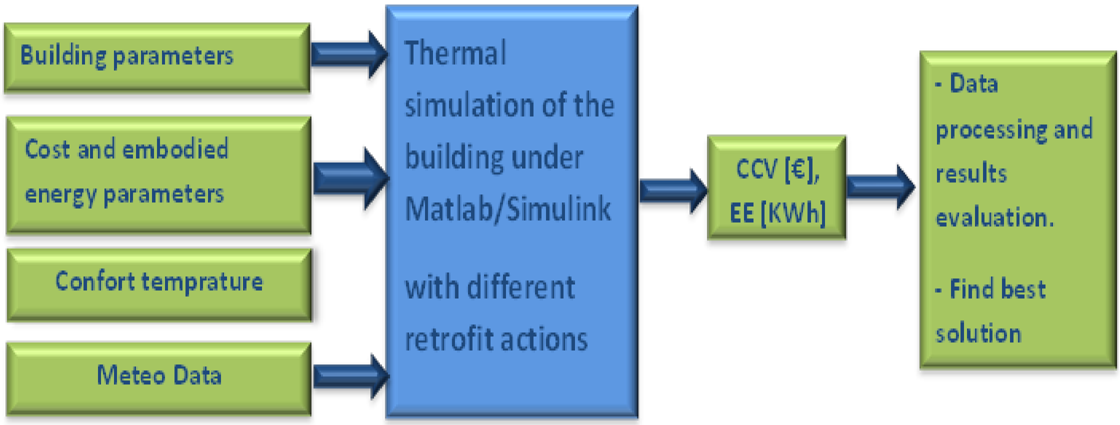

Fig. 1: Flowchart of proposed method

4 Case study and results

4.1 Building description and dynamic thermal simulation

A house in Bordeaux (*Fig. 2)* 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 m² (without considering basement)
- Surface of exterior walls : S_{ext} = 152.4 m²
- Glass surface : S_{glass} = 18.72 m²
- Surface of outside doors : S_{doors} = 5.5 m²
- Ceiling height : h_s = 3 m

Exterior surfaces are composed as follows:

- Exterior wall :
  - 1 cm of plaster (λ = 0.7 W/m.K)
  - 29 cm of stone (λ = 1.15 W/m.K)
- Outside door : 6 cm of wood (λ = 0.18 W/m.K)
- Ground floor ***:***
  - 10 cm of concrete (λ = 0.92 W/m.K)
  - 20 cm of stone (λ = 1.15 W/m.K)
- Ceiling :
  - 1 cm of plaster (λ = 0.7 W/m.K)
  - 20 cm of air (λ = 0.03 W/m.K)
  - 3 cm of wood (λ = 0.18 W/m.K)
- Windows: 4 mm of single glazing.

Fig. 2 : Selected building as case study

Results for dynamic thermal simulation (*Fig.3)* with meteorological data of 2011 give 17506 KWh/year of energy consumption for heating (close to invoice 17216 kWh / year).

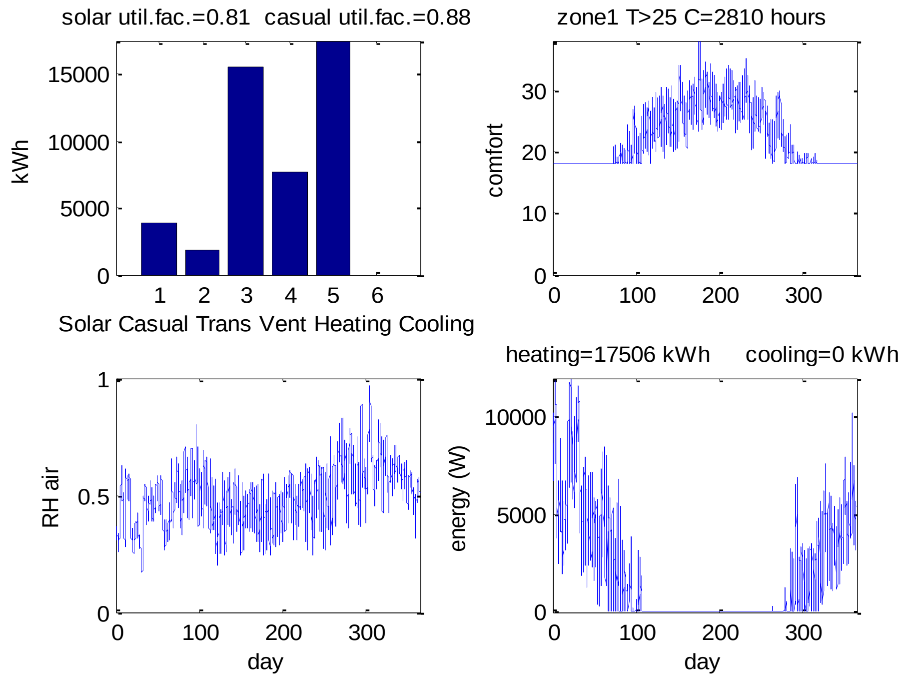

Fig. 3: Results of dynamic thermal simulation of the existing house (Before renovation actions)

4.2 Parametric study and optimization results

Our methodology compares global costs and life cycle energies of retrofitting actions for different combinations in the discrete domain. A set of six hundred and forty height simulations combining different parameters (insulation type and thickness, windows frame material and glazing type, etc.) have been executed. Developed routine runs for up to one hour (with Intel Core Duo processor (CPU T7250 @2 GHz)). 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

Results show that:

- A thorough energetic renovation (solution (2)) is not interesting from a financial point of view.
- In this case study (and may be for houses in Southwest of Europe), using triple glazing is not enough benefit from both financial and energetic point of view.
- 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.

5 Conclusions

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.

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