Cost hypothesis in optimization models for thermic renovation and change in heating systems in France

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Abstract

Within the framework of the fight against global warming and the national low-carbon strategy, it is essential to carry out the necessary energy renovations in the most appropriate way so that they cost us the least, both economically and environmentally. It is therefore essential to provide local authorities with the best tool to simulate renovations on their territory. Following the development of *Shape Optim*, a building-by-building energy renovation optimizer, this research work challenges the cost assumptions of this optimization model, using different sources and different comparison methods. While the method of assessing the costs of the heating system is satisfactory, it appears that the linear costs of insulation need to be both updated and made more complex, taking into account more volume or age effects, or fixed labour costs.

INTRODUCTION

In order to preserve our civilisations, our population, our level of development and our environment, it is essential to fight global warming, its extent and its consequences, and therefore to profoundly transform our energy systems [1]. Embarking on an energy transition to drastically reducing our greenhouse gas emissions implies a dual approach. The first is to substitute energy sources in order to use less carbon-based energy. The second is energy efficiency.

The residential building sector is one of the predominant sectors in the total final energy consumption as well as in the CO2 emissions, hence its key role in the energy transition. Moreover, this sector has the most accessible and cost-effective emission reduction potential by combining the two greenhouse gas reduction levers [2]. Insulating a building or installing a ventilation system is part of energy efficiency, and changing the heating system is part of energy efficiency [3].

In this context, the recent French National Low-Carbon Strategy aims at a drastic decrease of greenhouse gas emissions in this sector: -49% of emissions between 2017 and 2030, and -88% between 2030 and 2050. This corresponds to 700,000 annual renovations to BBC level from 2030 [4]. Moreover, not only does it allows less carbon emissions, energy renovations are positive for environmental impacts and indoor quality [5]. Therefore, numerous national policies are carried out: the multi-year energy programmes, which require the renovation of all buildings with energy performance diagnosis marked F or G before 2028, and the stimulus plan, which has injected 2 billion euros into this sector between 2021 and 2022.

To help local authorities and other stakeholders to transform their building stock through effective public policies, the French Environment and Energy

Management Agency *(ADEME), Mines ParisTech* and *le Centre Scientifique et Technique du Bâtiment (CSTB*) have joined forces to develop a tool to optimise energy renovations in a given territory. This tool consists first of all of extremely precise modelling of the territory, building by building, as well as technical and economic optimisation, via the optimiser called *Shape Optim*. This project is being developed through various research projects that have been completed or are underway, and this present work is set in this framework. It was decided to improve the optimisation tool in terms of the model's cost assumptions, as these data are central to the results of the optimiser.

The focus here is on the costs of insulating the various parts of a building envelop (walls, windows, floors, attics) as well as the costs of changing heating systems and installing ventilation systems. Modelling and generalising the amount of these costs is complex due to various phenomenon: the dispersion of prices on the market for the same energy service, the economic mechanisms of market movement (state of competition), the quality of the initial insulation or the correct sizing of the heating capacity. Since it is a decision support tool for local authorities, the *Shape optim* tool must integrate the cost for individuals in this model, and must therefore take into account the (variable) cost of materials, the (fixed) cost of moving labour or the real cost after potential subsidies and financial incentives.

METHODS

In order to challenge the cost assumptions of the optimisation model, I have used a threefold approach. The first approach consists of a direct comparison of data on unit costs or costs per m² of energy renovation works. This allows to know if the prices observed on the market are indeed those of the optimizer. The second approach is to compare the components of the different costs and thus to assess whether the *Shape Optim* method of calculating a cost is the right one. The third approach is a comparison based on the results of the optimizer: do we see the same correlations between the costs and various building characteristics (year of construction, geographical localization…) ?

RESULTS

Firstly, I worked on the assumptions currently present in the *Shape optim* model, via the work of Antoine Rogeau's thesis [6].

Concerning the heating system, the cost is composed of the maintenance cost, the renewal cost, the optional extra cost of replacing the heat emitter, the residual value as well as the investment cost which includes the installation cost and the price of the heat generator. To determine the latter, Rogeau and al. carried out a thorough techno-economic analysis and added the construction cost of the system (a fixed cost), and a linear cost, weighted by the peak heat demand of the building, assessed using the precise data of the building. This is the great advantage of building-by-building modelling: it allows to get as close as possible to the reality of a house. The cost comparisons on heating systems were not conclusive as the *Shape Optim* model is so much more precise whereas other sources used means and other statistical data to assess such costs.

Concerning the walls, although the modelling of the insulation is thermally advanced, in order to have a final thermal state as realistic as possible, it was decided - still in A. Rogeau's thesis - to use costs per m² only, by insulation technology. Therefore, I studied on many comparisons.

First of all, between the optimizer as it is developed and A. Rogeau's thesis, it is observed that the optimizer does not make any difference in cost and technology between fitted attics (insulation under slopes) and lost attics (insulation on the ground of the attic). Furthermore, I have observed that, when used, only a very small number of technologies appear in the optimisation results, regardless of the constraints imposed on the optimiser. For external wall insulation, only one technical solution is used against four possible ones. For internal wall insulation, the same ratio of one out of four is found, for the floor it is one out of five and for the roof it is one out of seven possible. This may reflect an exaggeration in the costs of unused technologies.

I then used the study by the *Observatoire des Coûts de la Rénovation énergétique* to test the cost assumptions [7]. They note several interesting effects. First, for the same renovation, the cost is higher for older houses: it is 113€/m² on average for houses built before 1948 against 97€/m² for those built after 1974. Secondly, they observed a variation in surface costs according to the total surface area, through a volume effect. For example, for houses with more than 115 m² of living space, renovation costs are around €86/m² compared to €125/m² for houses with less than 85 m². In order to consolidate the cost assumptions of *Shape Optim*, these two conclusions should be corroborated by the same analyses of the optimizer results (approach n°3). However, since the wall insulation costs are surface based, there is no volume effect per m² or extra cost for older houses.

Finally, I compared *Shape optim* to the ADEME price study, which collects and analyses the prices and characteristics of more than 12,000 energy renovation projects carried out by French households [8]. Firstly, they observed that the correlation between the insulated area and the cost of insulation is not equal to one, as in the *Shape Optim* results, and, moreover, depends on the insulation action. It is 0.8 for external wall insulation, 0.63 for windows, and 0.45 for attic insulation. This corresponds to the fixed cost in these services, which is not only to be added to the model but depends on each technology. Secondly, ADEME also observed the components of the insulation prices and found that the share of labour is higher for external wall and crawl space insulation (50% of the price) than for lost attic space (30%). Thirdly, the ADEME price study provides raw data on the prices observed on the market and this in surface cost. The comparison with the *Shape Optim* data is more direct. The compared data can be seen in Annex 2 and we observed especially that insulation of walls from the inside and floor insulation costs were misevaluated.

DISCUSSION

Although it is tempting, in the light of these results, to make the calculation of insulation areas more complex, a number of difficulties must be recalled. Firstly, developing a new method of evaluating the cost of insulation that takes into account, among other things, the various effects mentioned (date of the house, total surface area to be covered, fixed labour share) is complex and has, for my part, been inconclusive. Secondly, it should be remembered that costs vary greatly from one craftsman to another, from one model to another, and also depend on the total size of the project - all the more so with of the development of “global renovations”. It can also vary with the renovation financial incentives. On this last point, if the idea is to represent the aid actually received by individuals today, we come up against the problem of regulatory change, the lack of tax data on occupants and also the diversity of the amounts paid to individuals in the form of Energy Savings Certificates (*CEE*), since it is the private or public organisations that pay them that determine the amount of the euro per *CEE*.

The results of these comparisons show that while the costs of the heating systems seem satisfactory, the linear costs of the insulation measures existing today in the *Shape Optim* assumptions need to be updated, in particular the insulation of walls from the inside and floor costs. In addition, we have highlighted that it would be relevant to make the evaluation of the costs of insulation surfaces more complex by including effects such as the volume effect or wear and tear. Finally, in order to improve *Shape Optim*, we need feedback from those for whom it is intended, to know if it is more relevant to work on the development of new costing methods or if we should focus, for example, on adding functionalities relevant to a local authority such as the possibility to simulate public policies.

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ANNEXES

Annexe 1 : Table of Shape available technologies (left) and the technologies observed as Shape Optim output (right)

category	name	uf_cost
wall	Unchanged	0
wall	ITI_GW_Standard	120
wall	ITI_GW_Performant	150
wall	ITI_RW_Standard	150
wall	ITI_RW_Performant	170
wall	ITE_GW_Standard	130
wall	ITE_GW_Performant	180
wall	ITE_RW_Standard	140
wall	ITE_RW_Performant	190
floor	Unchanged	0
floor	GW_Standard	100
floor	GW_Performant	140
floor	RW_Standard	110
floor	RW_Performant	150
floor	PU_under_floating_concrete	400
roof	Unchanged	0
roof	GW_roul_Standard	60
roof	GW_roul_Performant	80
roof	RW_roul_Standard	65
roof	RW_roul_Performant	85
roof	RW_souf_Standard	50
roof	RW_souf_Performant	70
window	Unchanged	0
window	Vitrage_Standard	300
window	Vitrage_Performant	500

Solution	€/m²
Sol (GW_Standard)	**100**
Toit (RW_souf_Standard)	**50**
Mur – ITE (ITE_GW_Standard)	**150**
Mur – ITI (ITI_GW_Standard)	**120**
Fenêtre - Standard	**300**
Fenêtre - Performant	**500**

Annexe 2

	Etude des prix de l'ADEME 2019					**SHAPE**
Postes de travaux	Très basse HT	Basse HT	Prix médian	Haute HT	Très haute HT	Coût surfacique
Combles perdus	17	26	25	57	93	50
Rampants	27	48	70	89	182	50
Planchers bas	26	40	37,5	60	85	**100**
ITE	43	111	150	181	238	150
ITI	18	42	60	71	112	**120**
ITI lnc	18	42	60	71	112	x
Fenêtres double vitrage	250	400	600	800	1000	300 - 600