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# **Cost and Efficiency Assessment During Deep Energy Refurbishment Strategies: A Case-Study-Based Methodology**

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## **ABSTRACT**

The building sector is the largest energy consumer in France, it is responsible for more than 43% of the final energy consumption, ahead of transportation and industry. Since the Grenelle Environment, the government has set up a number of policy measures to overcome barriers to energy efficiency in the domestic sector, but it appears insufficient to reach the French objectives. To remove brakes to an efficient energy refurbishment and develop appropriate solutions to all stakeholders it's necessary to understand the performance of the current renovation system. This chapter focuses on process level to deal with a deep renovation. As methodology, a case study approach, including the description of human organization's level process, is used to identify new ways to deal with energy refurbishment in private dwellings in a French context. Two initiatives are compared on the basis of the roles and responsibilities of stakeholders to achieve the various tasks in the refurbishment process. Results show the difference in cost and effectiveness of energy measures implemented according to the strategy and the approach adopted in a refurbishment decision-making process.

**Keywords:** Deep energy refurbishment, case study, key phases for a large-scale renovation, deep refurbishment process, cost effectiveness.

## **1. Introduction**

In France, the building sector is the largest consumer of the final energy ahead of transportation and industry. It is responsible for more than 43% of the final energy consumption, which generates approximately 23% of greenhouse gas (GHG) emissions (PNAEE, 2011). Furthermore, the development of climate change adaptation must take into consideration a difficult economic context, with a constant increasing energy cost and development of the fuel poverty that became a growing concern for numerous actors. Furthermore according to the draft law of the energy transition the nuclear energy production have to decrease from 80% to 50% in electricity generation for 2025 (MEDDE, 2015).

The building sector is the least dependent in the fossil fuels. So according to the ecological and social context energy refurbishment offers a great opportunity to reduce global energy consumption, GHG emissions and fuel poverty.

In order to meet the international targets with regard to factor 4, i.e. achieving a 75 % reduction in GHG emissions (UNFCCC, 1998), a wide range of measures were deployed at a national and local level to stimulate building renovation. In spite of that refurbishment rate remains low with an insufficient level of renovation. A first assessment conducted in 2012 shows a delay in achieving France's Grenelle Environment objectives : 150,000 homes were renovated against 500,000 expected (Charlier & Risch, 2012; Sénat, 2013). In 2013, the French permanent observatory energy home improvements (OPEN) observed an average household investment of EUR 5210, where 68 % of refurbishment project concern only one work (OPEN, 2014) which impact from an energy performance

perspective is not measured. So to achieve the national and international objectives new approaches are needed to overcome barriers to an efficient energy refurbishment of existing buildings, so which measures can be implemented in regards to various stakeholders' motivations, objectives and barrier.

Therefore, this paper aims to study the approach of two initiatives launched in 2012 in the north east of France that allowed 441 households to overcome barriers to a deep energy refurbishment.

The next part highlights the refurbishment measures in France to contextualize the initiatives approach; section 3 presents the both initiatives approach to carry out a deep renovation. Finally, in section 4 our study is discussed as well as implications for further works.

## 2. Energy efficiency of existing buildings in France

The refurbishment program is not only the implementation of renovation works. Various elements have to be considered to determine, implement and apply the most cost-effective retrofit technologies. According to (Ma, Cooper, Daly, & Ledo, 2012), to achieve a building renovation the process of refurbishment must consider five key phases : Project Setup and Pre-retrofit Survey; Energy Auditing and performance Assessment; Identification of Retrofit options; Site Implementation and Commissioning and, Validation and Verification. These key phases have to take into account factors that impact the choice of the measures that will be implemented. Those factors include the policies and regulations (Baek & Park, 2012), the homeowners' expectations and their financial resources (Ferreira, Duarte Pinheiro, & de Brito, 2013) ; the retrofit technologies (Jakob, 2006), the building specific information (Singh, Mahapatra, & Teller, 2013) and, human factors and other uncertainty factors (Ma et al., 2012).

In order to achieve the international targets, the French government aims a reduction of 38% in the energy consumption of buildings by 2020 and 75% by 2050. That means a thermal improvement of 500 000 homes each year by 2017, to reach a national consumption of 150 kWh/m<sup>2</sup>/yr by 2020 and 50 kWh/m<sup>2</sup>/yr by 2050, compared with 240 kWh/m<sup>2</sup>/yr today (Pelletier, 2009). Since the Grenelle Environment a number of policy measures has been set up to achieve these objectives.

At a national scale, public policies took key measures to support householders in the project (Atanasiu & Kouloumpi, 2013). Three axes make the framework of the key measures (Lorraine.eu): regulation, sensitization, and incitement.

The regulation measures for existing buildings defines an overall performance target for constructions over 1,000 m<sup>2</sup> completed after 1948. Below that area a minimum performance levels for replaced or installed elements is requested (RT 2005) (Molle & Patry, 2013; Plan Bâtiment Durable, 2014). A sales transaction or a signature of a rental agreement requires a diagnosis of energy performance directed by a qualified expert. It assesses the thermal quality of housing based on standard usages and informs of the produced level of GHG emission. According to the results, the expert makes recommendations for improving the thermal quality of the housing; however, works have a none-obligatory character.

Sensitization measures are made by means of information campaigns such as forums or advertising; and by EIE<sup>1</sup> who advise private householders on energy efficiency and renewable energy sources. They inform about existing financial and technical solutions to improve the energy efficiency in the dwellings, they route homeowners to approved enterprises RGE<sup>2</sup> for the refurbishment activities and engineering offices for the thermal study. In France, 240 spaces exist with more than 410 advisors.

Incitement measures take various form of financial aid to support energy auditing, the project managing, the purchase of efficient materials and the implementation of some works that favour the buildings' energy efficiency. Subsidies depend on various parameters as the CSTB<sup>3</sup>'s certification of the both used materials and equipment and

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<sup>1</sup> EIE: Energy Info Spaces (Espaces Info Energie in French)

<sup>2</sup> RGE (Reconnu Garant de l'Environnement) is a voluntary qualification intended for craftsmen and companies specialized in projects supporting energy efficiency and installation of equipments powered by renewable energies. Since September 2014 RGE craftsmen and companies is required for the zero rate eco-loan and since January 2015 for the Sustainable Development Tax Credit.

<sup>3</sup> CSTB (Centre Scientifique et Technique du Bâtiment in French) public institution dedicated to research, expertise, evaluation, certification and knowledge dissemination in the area of construction products, buildings and their integration within the residential area.

have to be implemented by RGE enterprises. It also varies according to income levels, the type and number of works carried out and performance level to be reached. According to the Department of Housing the incentive measures take the form of public and private subsidies (Ministère du Logement de l’Egalité des territoires et de la Ruralité, Ministère de l’Écologie du développement durable et de L’énergie, ADEME, ANIL, & ANAH, 2015).

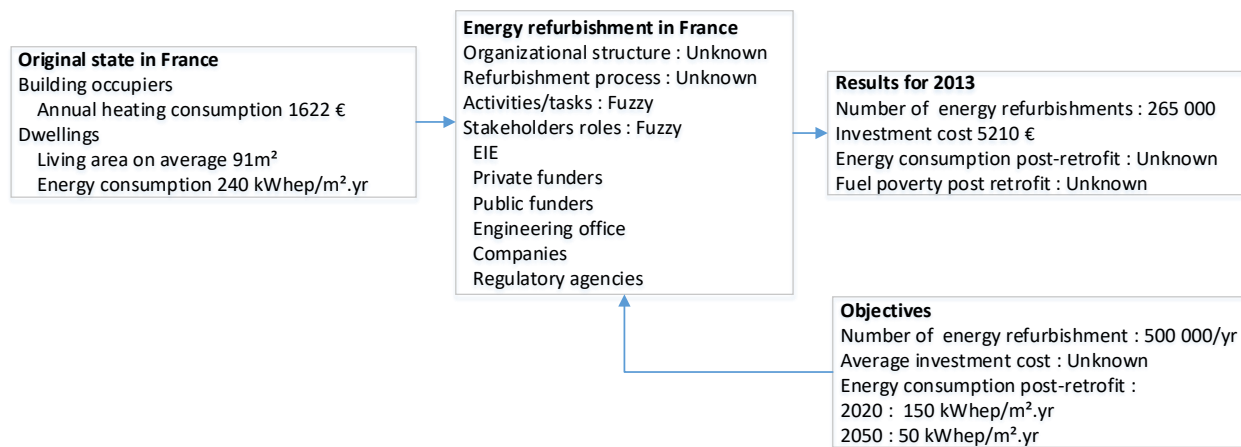
Thus, public aids take the form of national subsidies from Anah<sup>4</sup> with the Live Better program (Desforges, 2011; MEDDE & METL, 2014) ; “energy cheque” ; regional and local subsidies from the local authorities ; Tax benefices as the Sustainable Development Tax Credit (CIDD); a reduced VAT to 5.5% for the work performed by installers that hold the quality sign RGE (MEDDE, 2013) and subsidized loans, such as the zero rate eco-loan (Eco-PTZ).

Private subsidies take the form of energy savings certificates from energy suppliers (electricity, gas, domestic fuel oil and heating sellers).

Currently to realize an efficient building retrofit work *i.e.* a deep renovation the preferred solution from ecologic and economic point of view (Hermelink, 2011), households have to define the most cost effective retrofits; deals with complicated administrative procedures for applications grants and financial records fixtures (Nair, Gustavsson, & Mahapatra, 2010); coordinate the different trades for a global approach (Tuominen, Klobut, Tolman, Adjei, & de Best-Waldhober, 2012); find adequate financial solutions when resources are too low (Achtnicht & Madlener, 2014; Stieß & Dunkelberg, 2013) and spend time to realize all that work (Friege & Chappin, 2014; Stieß & Dunkelberg, 2013), that implies interact with the various stakeholders of the renovation system if the different phases of a refurbishment process are identified. A customer in charge of such tasks must have technical, financial and organizational knowledge and skills to achieve a deep refurbishment.

To sum the lags in matter of energy efficiency in private dwelling is the result of numerous economical and non-economic barriers that complicate the identification, implementation and evaluation of refurbishment measures.

Friege & Chappin (2014) point out in their bibliometric research three important core areas focusing on technical options, incentive instruments, models and simulation, and an emerging cluster about understanding decisions. This area highlights economic and non-economic goals to implement an energy refurbishment, but the decision-making process remains fuzzy. The (Figure.1) summarizes known and unknown areas in France concerning energy refurbishment.



**Fig.1 Energy refurbishment in France**

Furthermore, in order to develop appropriate solutions to all stakeholders, it is necessary to consider new approaches that take into account decision-making process in the various phases of the energy refurbishment.

<sup>4</sup> Anah : National Agency for Habitat ( Agence Nationale de l’Habitat )

### 3. A case study research protocol

#### 3.1. Theoretical design and procedure

The research is conducted in line with the engineering innovation to identify new approaches to deal with energy refurbishment. According to Girodon *et al* (2015) to describe a human organization four main organizational models are required: the organizational structure model; the process model; the activity model and the role model. This chapter focuses on process level, leading to take close interest in the stakeholders' roles and the activities achieved in a refurbishment process. Case study approach adapted from Yin (2003) is used as shown in Figure 2 to identify and compare two approaches to deal with deep energy refurbishment.

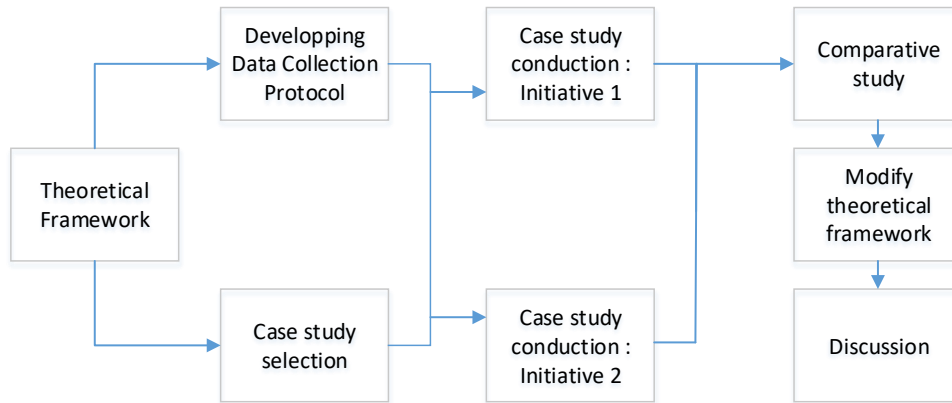


Fig. 2. Case study research : Design and procedure (adapted from Yin, 2003)

Two case studies with a similar size in terms of employees were selected before identifying and comparing their approach. They are located in a particular geographical context favoring fuel poverty and high energy consumption. Since 2012 (to the end of 2015), they enabled on one side 41 homeowners to carry out a deep energy refurbishment and 400 in the other.

In a first step individual interviews, according the Hunter (2015)'s methodology, were carried out with all the employees of the both cases to get a greater insight into the overall organization. It highlights the decision-making process and identifies the key phases of a renovation project. Each one described its activities, the methods and tools used to achieve an energy renovation. They indicate the conditions and the actors with which they interact. Interviews were iterative to formalize the stakeholders' roles in the activities and the deep energy refurbishment process.

These initiatives are recent which means data newly available to research. For both cases, only projects that endured two winters were considered in this chapter to improve the quality of data. For the first initiative 21 refurbishments were taken into account out of a total of 41 projects, and for the second 55 energy renovations out of a total of 400. Data were collected and analysed to evaluate the cost effectiveness of the refurbishment process.

Investment cost of each project was collected from craftsmen bills by differentiating total investment cost and investment that have a direct impact on energy efficiency.

Energy performances pre-retrofit and post-retrofit were obtained through thermal study reported in the audit report.

#### 3.2. Context of the case studies

The both initiatives are located in the north east of France and were launched in 2012 in a context that combine several factors leading to the need, from a different point of view, to achieve deep refurbishment. The climatic specificities of the geographic area located in the coldest zone in France (H1b zone) (Ministère du Développement durable, 2013) ; the old housing stock, over a third party built before 1915 and over half before 1949 (DREAL, 2014); the living area of 75 % of dwellings exceed 70m<sup>2</sup> as compared with a national average of 64 % (Insee, 2015) impact directly the energy consumption which is on average of 318 kWh/m<sup>2</sup>/yr per housing compared with a national average of 240 kWh/m<sup>2</sup>/yr (Insee, 2010); The annual energy bill per household is 1900 € (DREAL,

2014). As consequence, the energy vulnerability impacts a third party of the households of these region (Insee, 2015). Boardman (1991) defines the fuel poverty as households whose fuel expenditure on all energy services exceeded 10% of their income. In France, according to the Loi Besson (31<sup>st</sup> May 1990) a person “is in a situation of fuel poverty, when he has difficulties to have the necessary energy to satisfy its elementary needs owing to inadequate income or to the housing conditions”. The fuel poverty depends on three major factors low income , energy prices and the building energy performance (Devalière & Teissier, 2014; EPEE project, 2008; Fabbri, Tronchin, & Tarabusi, 2014). In view of the economic, social and geographical context, these regions represent a major challenge to meet the energy consumption and the households’ fuel poverty.

EDF (the French electricity producer and supplier), the main investor in these programs, is involved in Cigéo project (highly radioactive waste storage project of Bure-Saudron) which implies the support of the economic development of Meuse and Haute-Marne departments in the energy axe. So EDF accompany local actors in their actions with regard to energy conservation and reduction of CO2 emissions, by investing in these initiatives and by offering Eco advantages subsidies.

The Initiative 1 is a SCIC<sup>5</sup> launched in 2012 in the city of Commercy. It’s chaired by an elected with a general assembly composed of six colleges: energy companies; local authorities; local economic development partners; building professionals; owners / tenants and its employees. Its legal status considers the interests of all parts of a project. Thus the society has multi-objectives at multi-scales as the development of the local construction activity, revitalizing the territory, enhancing the purchasing power, distributing fairly the public aids, etc. Since 2012 it assisted 41 homeowners at various stages in the renovation process in the south of the department of Meuse (Table.1).

The Initiative 2 is an offer proposed by the energy supplier S.A EDF and it was also launched in 2012. The EDF’s trade sector aims to recover Energy Savings Certificates and the economic development service aims to develop the building sector revenue, enhance the purchasing power, reduce the fuel poverty and reduce the GHG emissions. Their services propose a thermal study and assistance to client for free. This program allowed 400 homeowners to realize a deep refurbishment (Table 1).

**Table 1 Focus area and purpose of both case studies**

	<b>Case study 1</b>	<b>Case study 2</b>
<b>Date of creation</b>	2012	2012
<b>Legal status</b>	Cooperative society of public interest	S.A EDF
<b>Focus area</b>	Climate zone H1 Department of South Meuse Homeowners and landlords Primary residence Single family home and apartment Building build before 1990	Climate zone H1 Departments of Meuse and Haute Marne Homeowners and landlords Primary residence Single family home and apartment Building build before 1990
<b>Purpose</b>	Development of the local construction activity Enhancing the purchasing power Revitalizing the territory Combining saving energy, sanitary condition and the housing quality Reducing CO2 emissions Reducing the energy consumption	Recovering Energy Savings certificates Reduce the heating demand Enhancing the purchasing power Development of the local construction activity Revitalizing the territory Reducing CO2 emissions Reducing the energy consumption
<b>Performance objectives</b>	Achieve a BBC Renovation level of energy consumption i.e 112 kwh.m <sup>-2</sup> .yr <sup>-1</sup>	Improve works not in compliance with the existing building regulations in term of thermal resistance Air tightness level: 1.2

<sup>5</sup> SCIC (Société Coopérative d'Intérêt Collectif in French): cooperative society of public interest

For the both case studies the common goal is to reduce the energy consumption, the fuel poverty, and to improve the indoor home quality. The first alternative aims a BBC Renovation<sup>6</sup> consumption i.e a final energy consumption at least 112 kWh.m<sup>-2</sup>.yr<sup>-1</sup>, and the second one achieves works that not conforming to the thermal regulation for existing buildings. To reach these targets only an effective measure to reduce energy consumption due to heating demand (Hermelink, 2011) is carried out. It consists in improving insulation of the house (walls, roof, ground floor, and openings), installation of better windows, improving air tightness of the building envelope and installation of ventilation (Risholt, Time, Kvande, & Hestnes, 2011) and only when it's necessary an adapted heating system is added depending on the energy demand. In order to ensure this, the first alternative provides paid services: thermal study, project management and performance contract services. The second one proposes a thermal study and assistance to the client (Table 2).

**Table 2 Solutions to deal with deep refurbishment**

	Case study 1	Case study 2
<b>Strategy</b>	Aims a final energy performance	Requirements of thermal regulation
<b>Services proposed</b>	Thermal study with Project management Energy performance contract	Thermal study with Assistance to client
<b>Method of calculation for thermal study</b>	Phhp <sup>7</sup> method 3 proposed scenarios: - Customer expectations -BBC energy consumption level -reducing energy consumption to the utmost	3CL <sup>8</sup> calculation method 1 scenario: Improve works not in compliance with the existing building regulations in term of thermal resistance
<b>Works</b>	Deep energy refurbishment: Insulation of the house: walls, roof, ground floor, and openings Improving air tightness of the building envelope Installation of dual flow ventilation Heating system	Deep energy refurbishment: Insulation of the house: walls, roof, ground floor, and openings Improving air tightness of the building envelope Installation of ventilation Heating system
<b>Financial solutions</b>	Public and private subsidies Zero rated loan Personal capital Additional loan	Public and private subsidies Zero rated loan Personal capital Additional loan
<b>Number of deep energy refurbishment</b>	41	400

## 4. Results

To understand and compare these cases studied, we investigated three aspects according to the different levels in the engineering innovation: the key phases and the process of deep energy refurbishment; the roles and responsibilities of stakeholders in the refurbishment process; and cost effectiveness evaluation of both cases.

### 4.1. Key phases and refurbishment proposal for a deep energy refurbishment

To determine, implement and verify the most cost-effective solutions, the refurbishment process includes similar or different tasks. For the both cases five key phases can be identified (see table 3):

- Awareness and formulation of the scope of the work
- Identification of the retrofit options and cost benefit evaluation
- Selection of the best alternatives and preparation of the implementation
- Site implementation, verification during retrofit activities and commissioning
- Validation and verification

<sup>6</sup> Label BBC Renovation (Bâtiment Basse Consommation) requires primary energy consumption below 80 kWh/m<sup>2</sup>.an depending on the climate zone and the altitude. The primary energy consumption takes the form  $C_{ep,max} = 80 \times (a+b)$ , where "a" is the climate zone coefficient and "b" is the altitude coefficient. Calculation is performed by using the conventional method.

<sup>7</sup> PHPP (Passive House Planning Package) "is a spread sheet design and compliance tool produced by the Passivhaus Institute to model the performance of a proposed Passivhaus building" (Moran, Blight, Natarajan, & Shea, 2014)

<sup>8</sup> 3CL : Conventional Consumption Calculation for Lodging (Calcul Conventiennel des Consommations des Logements)

Table 3 Key phases in a sustainable building retrofit program

	Initial model	Elements for new model based on case study	
	Sustainable building retrofit program (Ma et al, 2012)	Study case 1	Study case 2
<b>Pre-retrofit activities</b>			
<b>Phase 1</b>	<b>Project setup and pre-retrofit survey</b>	<b>Awareness and formulation of the scope of the work</b>	
	Define scope of work Set project targets Determine available resources Pre-retrofit survey	Verification of project eligibility Socio economic diagnosis Technical economic diagnosis Customer awareness -Cost refurbishment -Existing subsidies -Financing requirements -Cost/benefits -process of refurbishment Client expectations	Verification of project eligibility -- -- Customer awareness -Deep refurbishment -Existing subsidies -Financing requirements -Cost/benefits -Process of refurbishment Client expectations
<b>Phase 2</b>	<b>Energy auditing &amp; performance assessment</b>	<b>Identification of retrofit options and cost benefit evaluation</b>	
	Energy Auditing Select key performance indicators Building performance assessment & diagnosis	Client data collection Building data collection Energy auditing Energy use baseline establishment Building performance assessment Risk assessment Identify possible retrofit measures Energy saving estimation Economic analysis Proposition of various scenarios Cost-benefit analysis Audit report	-- Building data collection Energy auditing Energy use baseline establishment Building performance assessment Risk assessment -- Energy saving estimation -- Recommendations work -- Audit report



<b>Phase 3</b>	<b>Identification of retrofit option</b>	<b>Selection of the best alternatives and preparation of implementation</b>	
	Energy saving estimation Economic analysis Risk assessment Prioritize retrofit options	Client review and explanation of the audit report Choice of the best alternative Distribution of the call for tenders Selection of craftsmen group Preparation of the technical records Validation of the types of works and materials Preparation of the financial package Submission for government grant Submission for zero interest loan Financial validation Declaration of the outdoor work	Client review and explanation of the audit report -- Draw up estimates Selection of the craftsmen and their representative Preparation of the technical records Validation of the technical records Preparation of the financial package Submission for government grant Submission for zero interest loan Financial validation Declaration of the outdoor work
<b>Retrofit activities</b>			
<b>Phase 4</b>	<b>Site implementation and commissioning</b>	<b>Site implementation, and commissioning</b>	
	Site implementation Test and commissioning	Coordination meeting Demand deposits and grants advances Implementation Verification during the work Airtightness testing Commissioning Demand for end housing grants	Coordination meeting Demand deposits and grants advances Implementation Verification during the work Airtightness testing Commissioning Demand for end housing grants
<b>Post retrofit activities</b>			
<b>Phase 5</b>	<b>Validation and verification</b>	<b>Validation and verification</b>	
	Post measurement and verification (M&V) Post occupancy survey	Consumption monitoring	Post occupancy survey

#### *Awareness and formulation of the scope of the work*

First of all, criteria for determining whether or not the project meets the initiative requirements, depending on the strategy adopted, for a deep refurbishment are set as the initial condition of the building, the date of construction, the occupancy status, the ability of homeowner to fund the aimed performance, etc...

Then customer is informed about the offer, the process for a deep refurbishment and the costs and possible benefits after the energy refurbishment. A socio-economic diagnosis (expectations, and available financial resources) and technical-economic diagnosis (building and equipment condition) is realized in order to estimate the possible cost of the renovation and the expected savings (thermal comfort, indoor air quality, energy saving). In order to go further targets are set depending on the technical, financial constraints and homeowner's expectations.

#### *Identification of retrofit options and cost benefit evaluation*

It aims to assess the initial state (technical building condition and socio economical customer condition) to propose the most suitable solutions for homeowners. Firstly, building information is collected on site to simulate the thermal behavior of the building then scenarios are proposed according to the strategy of the initiative. The objective is to find a trade-off between the cost effectiveness and the energy efficiency.

The first initiative optimizes technical and financial solutions by considering technical building constraints and socio economical customer constraints. The second study case determines the works not in compliance with the thermal regulation and within the homeowners financial possibilities the refurbishment can be carry out or not.

#### *Selection of the best alternatives and preparation of implementation*

This phase defines and validates technical, technological, financial and regulatory aspects of a deep energy renovation. The refurbishment works, and the technical characteristics of materials are defined, and then estimates are realized to choose the technical skills for a deep energy renovation. After adopting technical and technological choices, financial and regulatory validation is required before the implementation.

#### *Site implementation, verification during retrofit activities and commissioning*

The fourth phase concerns an organizational aspect of the refurbishment implementation. It's carried out after the regulatory and the financial acceptance. Before the implementation, working meetings are conducted to schedule and plan all the project process. To reduce faults during the refurbishment, verification and commissioning are done as work progress.

#### *Validation and verification*

The effectiveness of the implemented measures is evaluated in two stages. At the commissioning an airtightness test is realized to measure the air sealing quality, and during the use of the dwelling energy consumption is measured on the basis of real-time consumption monitoring or/and post occupancy survey.

According to the initiative and its own decision-making process, a renovation process is followed to identify, implement and verify to most suitable measures to homeowners (Figure.3). There are constructed and structured on the basis of the identified tasks and phases previously.

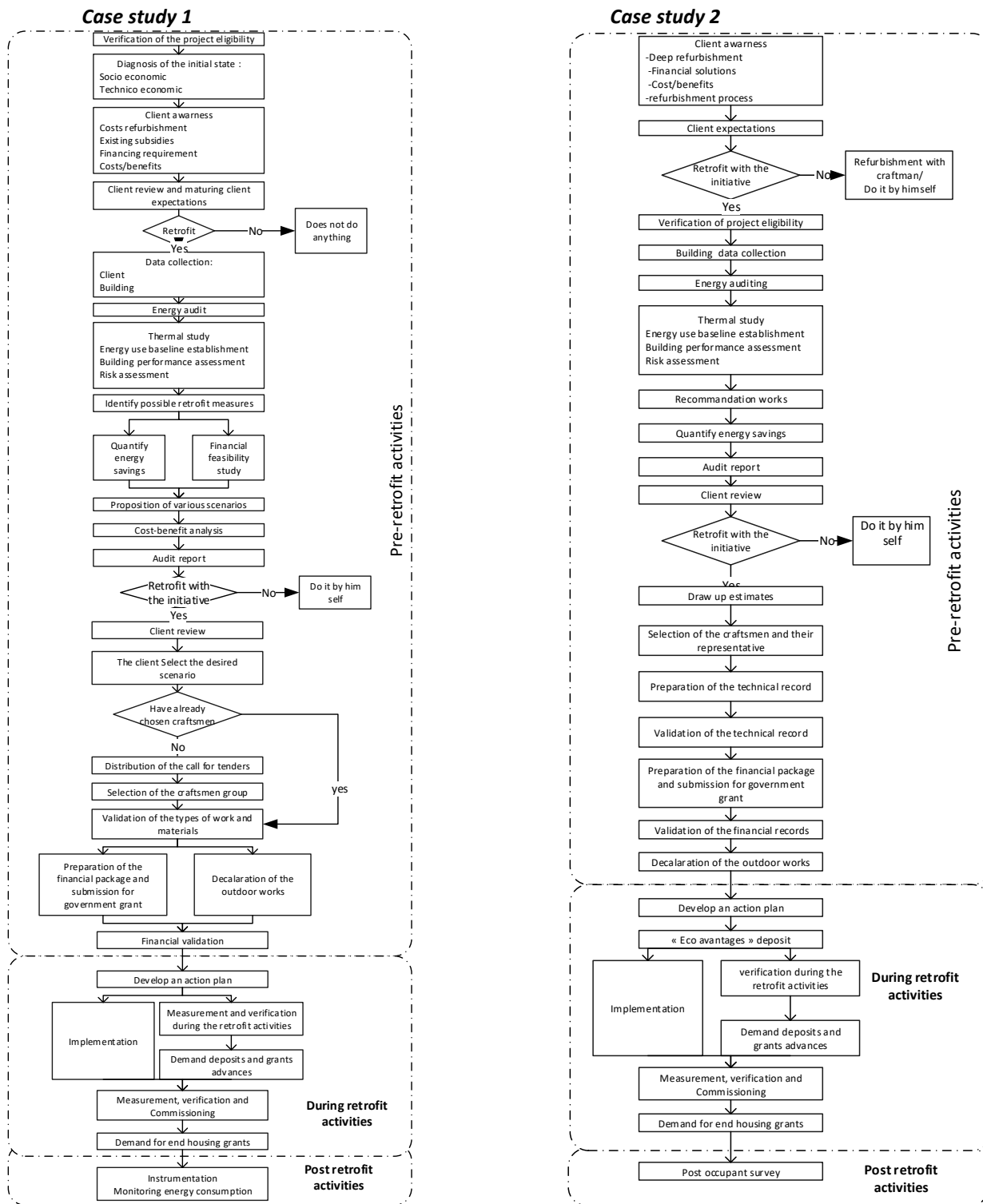


Fig.3. Decision-making processes of deep energy refurbishment according to the two studied strategies.

## 4.2. Stakeholders roles and responsibilities

The both cases studied follow the five phases identified by using their own tools and methods to determine, implement and verify the most cost-effective solutions. Various stakeholders involved in the renewal process were identified; this entailed six important aspects of a refurbishment project:

- project application: the customer
- coordination project: Initiatives
- technological aspect: suppliers
- technical aspect: Craftsmen, refurbishment companies, thermal diagnosticians
- regulatory aspect: regulatory agencies
- financial aspect: public and private funders

The Responsibility, Accountability, Consulted and Informed (RACI) matrix (OGC, 2011) is used to define the roles and responsibilities in relation to refurbishment activities in the energy renovation process. According to the initiative considered, the role and the responsibility of each stakeholder vary depending in the task to achieve (see Appendix I and Appendix II).

Responsible (R): the person or people responsible for correct execution-for getting the job done

Accountable (A): the person who has ownership of quality and the end result. Only one person can be accountable for each task

Consulted (C): The people who are consulted and whose opinions are sought. They are involved through input of knowledge and information.

Informed (I): the people who are kept up to date on progress. They receive information about process execution and quality.

Table 4 and Table 5 summarize stakeholders' roles and responsibilities in the various key phases of a deep energy refurbishment.

**Table 4 Stakeholders' roles and responsibilities during the key phases of a deep energy refurbishment**

Key phases	Initiative 1			
	R	A	C	I
<b>Awareness and formulation of the scope of the work</b>	Int1 -- -- --	Int1 -- -- --	-- Cust Cos BA PubFun	-- Cust -- -- --
<b>Identification of retrofit options and cost benefit evaluation</b>	Int1 -- -- -- --	Int1 -- -- -- --	-- Cust Cos BA PubFun RegAg	-- -- -- -- --
<b>Selection of the best alternatives and preparation of implementation</b>	Int1 Cust Cos -- -- --	Int1 -- -- -- -- --	-- Cust -- BA PubFun --	-- Cust -- -- PubFun RegAg
<b>Site implementation, and commissioning</b>	Int1 Cust Cos -- --	Int1 -- -- -- --	-- -- -- -- --	-- Cust Cos BA PubFun
<b>Validation and verification</b>	Int1 Cust	Int1 --	-- Cust	Int1 --

**Table 5 Stakeholders' roles and responsibilities during the key phases of a deep energy refurbishment**

Key phases	Initiative 1			
	R	A	C	I
<b>Awareness and formulation of the scope of the work</b>	Int2 -- Cos -- --	Int2 -- Cos -- --	Int2 Cust -- BA PubFun	-- Cust -- -- --
<b>Identification of retrofit options and cost benefit evaluation</b>	ThDiag	Int2 ThDiag	Int2	Int2
<b>Selection of the best alternatives and preparation of implementation</b>	Int2 Cust Cos -- -- --	Int2 -- Cos -- -- --	Int2 Cust Cos BA PubFun --	Int2 Cust Cos -- PubFun RegAg
<b>Site implementation, and commissioning</b>	Int2 Cust Cos ThDiag -- --	Int2 -- Cos -- -- --	-- -- Cos -- -- --	-- Cust Cos -- BA PubFun
<b>Validation and verification</b>	Int2 Cust	Int2 --	-- --	-- --

Cust: Customer  
Int2: Initiative 2  
Int1: Initiative 1  
BA: Bank  
ThDiag: Thermal diagnostician

Cos: Companies  
RegAg: Regulatory agencies  
PubFun: Public funders  
--: No stakeholder

At first customer is informed about the process and then consulted to assess the available resources and the client expectations. Then, during the next phases he takes part in the process either to choose the suitable alternative or achieve administrative aspects of the project. In the decision-making process companies' role is to provide technical skills to a deep energy refurbishment, the identification and the evaluation of most suitable measures is performed by the thermal diagnostician according to the initiative criteria. The public and private funders are consulted about their requirements to define the measures that are implementable or not. The regulatory aspect occurs when the project is set, regulatory agencies decide if the project is accepted or not.

### 4.3. Cost effectiveness

According to (Penna, Prada, Cappelletti, & Gasparella, 2014)'s model, results of these case studies can be examined from two aspects : the cost effectiveness of the refurbishment program and the energy use needed post-retrofit.

Table.6 shows the level of investment reached of each initiative. The medium cost is the average costs for the projects considered in the study. Maximum value is the highest level of investment reached by a project and minimum is the cheapest project.

Investment cost on energy is distinguished from the total investment of the renovation project. The total investment cost represents cost of materials, labor, and the services provided by initiative 1 (thermal audit, engineering management and performance contract). The service cost of the second initiative is for free. It includes the investment on energy retrofit and ancillary works as painting, electrics, plumbing, etc.

The investment cost on energy retrofit concerns works impacting the energy efficiency of dwellings i.e. the insulation, sealing, ventilation system and heating system.

**Tableau 6 Investment cost**

	Initiative 1	Initiative 2
<b>Total investment cost ( € )</b>		
<b>Medium</b>	78 642	33 220
<b>Maximum</b>	119 860	73 643
<b>Minimum</b>	43 161	5 657
<b>Investment cost on energy retrofit (€)</b>		

<b>Medium</b>	63 711	23 365
<b>Maximum</b>	86 356	46 275
<b>Minimum</b>	35 543	3 194

Table 7 summarizes the effectiveness of the implemented measures by comparing the Energy use needed post-retrofit and the cost for a saved kWh for each initiative. The energy use needed for heating pre-retrofit and post-retrofit expressed in (kWh. m<sup>-2</sup>.y<sup>-1</sup>) is the energy estimated according to the thermal study assuming an indoor temperature of 18°C. For the first alternative the energy consumption is estimated by the PHPP calculation method and a margin error of 15% for homeowners and 20% for landlords is considered. Values represent the maximum annual heating need under a normal dwelling use. For the second initiative the energy consumption is simulated by the conventional method 3CL and represents the minimum of the energy heating needed after implementing the refurbishment measures.

The cost effectiveness of the refurbishment program is expressed by Euros per kWh saved (Harmelink, Nilsson, & Harmsen, 2008). The values are given by dividing the investment cost on energy retrofit by the energy saved. The energy savings are given by the difference of the Energy consumption pre-retrofit (measured or calculated) and the energy use measured (or estimated) post-retrofit expressed in kWh (AEPKA, 2004). An average calculation of all project energy use pre-retrofit and post-retrofit gives the medium value for each initiative. Maximum and minimum are the highest and the lowest, respectively, observed value among the projects considered in this chapter.

**Tableau 7 Effectiveness of implemented measures**

<b>Results of measures implementation</b>	<b>Initiative 1</b>	<b>Initiative 2</b>
<b>Energy use pre-retrofit (kWh.m<sup>-2</sup>.y<sup>-1</sup>)</b>		
<b>Medium</b>	353	446
<b>Maximum</b>	579	982
<b>Minimum</b>	114	168
<b>Energy use post retrofit (kWh.m<sup>-2</sup>.y<sup>-1</sup>)</b>		
<b>Medium</b>	97	140
<b>Maximum</b>	180	295
<b>Minimum</b>	49	32
<b>Euros per kwh saved (€/kwh)</b>		
<b>Medium</b>	2.64	1.20
<b>Maximum</b>	6.21	6.43
<b>Minimum</b>	0.66	0.13

The investments requirements, for the first alternative are more important than the second one. The costs varies from 35 543 Euros to 86 356 Euros for an energy performance comprised between 49 kWh.m<sup>-2</sup>.yr<sup>-1</sup> to a maximum of 180 kWh.m<sup>-2</sup>.yr<sup>-1</sup>. While the second case requires investments from 3 194 Euros to 46 275 Euros for energy consumption comprised between 32 kWh.m<sup>-2</sup>.yr<sup>-1</sup> to 295 kWh.m<sup>-2</sup>.yr<sup>-1</sup>. That implies an average of investment per kWh saved at least twice as expensive in the first case.

## 5. Conclusion

Prior works has investigated new approaches to deal with deep energy refurbishment. Two similarly-sized initiatives launched at the same time in a geographical context which favour the fuel poverty and high energy consumption were selected. Both with their specific strategy carry out a large-scale energy refurbishment to reduce the final energy consumption. The first initiative aims a final energy performance post-retrofit at least equivalent to BBC Renovation level. The second targets works that don't follow France's existing thermal regulations (RT 2005). After identification and comparison of the activities in the refurbishment process, it turns out that each initiative adapts its offer, tasks, methods and tools to identify, implement and verify the most suitable measures; however same key

phases are observed. During these phases stakeholders' roles and responsibilities vary from an initiative to the other and that generates two different decision-making processes for homeowners. The investigation indicates both initiatives are present during the five phases with different roles; the first one with its "one-stop-shop" achieves all tasks for the whole renovation, so homeowners have a single contact. The second case assists customer all along the refurbishment process. It coordinates various stakeholders and distributes tasks in order to facilitate their accomplishment.

In this research we evaluate the investment needs depending on the final energy consumption needed in heating post-retrofit. Requirement are roughly of 63 000 Euros to achieve an average of final energy consumption of  $97 \text{ kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$  and 23 000 Euros for an energy heat post-retrofit of  $140 \text{ kWh}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ . That implies a cost per kWh saved of 2.64 Euros for the first initiative and 1.20 Euro for the second alternative.

These findings extend those of Ma et al. (2012), confirming that an overall refurbishment process follows key phases to identify, implement and evaluate the most suitable measures. In addition, our study emphasizes the importance of considering refurbishment in existing buildings from an organizational point of view, it enables to have an overview of the renovation system (see Appendix III). Focusing on process level helps to identify tasks, stakeholders of an energy refurbishment and their roles and responsibilities in this process.

This study therefore indicates that results, in terms of energy refurbishment implementation rates and energy performance level, vary depending on the initiative structure and adopted strategy. These impact stakeholders' roles, methods and tools in the refurbishment process, and play a determining role in initial investment requirements and benefits post retrofit.

The qualitative strategy helped a substantial gain in energy consumption with a high need investment, as a result limited number of projects was achieved. The quantitative strategy allowed to a significant number of homeowners to reduce energy consumption for a lower level than the first alternative, so the investment requirements are lower.

Despite of different strategies and approach both alternatives succeeded in the implementation of a large scale works by the project support that structure relationships by taking into account the requirements for every stakeholder involved, and then the refurbishment process is operated so as to optimize the technological, technical and financial solutions. Thus the whole refurbishment process is organized and structured to achieve the various key phases identified.

However, some limitations are worth noting. Although both initiatives study give a first assessment of the cost and benefits of a deep energy refurbishment, time and the same method should be given for their evaluation.

The two initiatives used different calculation method to assess the energy needed for heating. One use PHPP method to guarantee the consumption and consider a margin of error. The other uses the conventional method to estimate a minimum of energy demand and its results are not guaranteed. So, it doesn't allow an accurate comparison between the values of the both initiatives.

The first initiative passes on the charges for the provision of services on the price of the energy refurbishment, while the second one offers this service. That doesn't allow an accurate evaluation of the cost and benefit of the second strategy.

Action area for the first initiative is limited to the south of the Meuse department while the second one acted in a larger area which represents two departments (Meuse and Haute Marne).

Future work should therefore take into account some parameters to evaluate the cost effectiveness of the both structures. Same calculation method should be used to evaluate the heat energy demand post retrofit for both initiatives. The financial viability should be considered to assess the energy performance of a major renovation under the two strategies. The cost effectiveness of the both cases was studied by the energy efficiency and investment requirements, but what are the implications from an environmental, sanitary, social and economic point of view. To define the most suitable solutions and the required resources, costs and benefits must be evaluated from various values.

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Appendix I: RACI matrix of refurbishment tasks, case study 1

	<b>Refurbishment process tasks</b>	<b>R</b>	<b>A</b>	<b>C</b>	<b>I</b>
<b>Pre-retrofit activities</b>	Verification of project eligibility	Int1	Int1	--	Cust
	Socio economic diagnosis	--	--	Cust	--
	Technical economic diagnosis	Int1	Int1	--	--
	Client awareness	Int1	Int1	BA; PubFun; Cos	Cust
	-cost refurbishment	--	--	Cos	Cust
	-existing subsidies	--	--	PubFun	Cust
	-financing requirements	--	--	--	Cust
	-cost/benefits	--	--	--	Cust
	Client expectations	Int1	Int1	Cust	--
	Client data collection	Int1	Int1	Cust	--
	Building data collection	Int1	Int1	Cust	--
	Energy auditing	Int1	Int1	--	--
	Energy use baseline establishment	Int1	Int1	--	--
	Building performance assessment	Int1	Int1	--	--
	Risk assessment	Int1	Int1	--	--
	Identify possible retrofit measures	Int1	Int1	Cos; PubFun; BA; RegA	--
	Energy saving estimation	Int1	Int1	--	--
	Economic analysis	Int1	Int1	--	--
	Proposition of various scenarios	Int1	Int1	--	--
	Cost-benefit analysis	Int1	Int1	--	--
	Audit report	Int1	Int1	--	--
	Choice of the best alternative	Cust	Int1	--	--
	Distribution of the call for tenders	Int1	Int1	--	--
	Selection of craftsmen group	Cust	Int1	--	--
	Validation of the types of works and materials	Int1; Cust; Cos	Int1	--	--
	Preparation of the financial package submission for government grant	Int1	Int1	Cust; PubFun;BA	--
Declaration of the outdoor work	Int1	Int1	--	PubFun	
Financial validation	Int1	Int1	--	RegA	
		Int1	Int1	PubFun;BA	Cust
<b>Retrofit activities</b>	Coordination meeting	Int1; Cos; Cust	Int1	--	--
	Demand deposits and grants advances	Int1	Int1	--	--
	Implementation	Cos	Int1	--	Cust
	Verification during the work	Int1	Int1	--	Cos
	Final Airtightness testing	Int1	Int1	--	Cos
	Commissioning	Int1	Int1	--	Cos; Cust
	Demand for end housing grants	Int1	Int1	--	PubFun; BA
<b>Post retrofit activities</b>	Consumption monitoring	Int1; Cust	Int1	Cust	Int1

Cust: Customer

RegAg: Regulatory agencies

BA: Bank

--: No stakeholder

Cos: Companies

Int1: Initiative 1

PubFun: Public funders

Appendix II: RACI matrix of refurbishment task, case study 2

	<b>Refurbishment process tasks</b>	<b>R</b>	<b>A</b>	<b>C</b>	<b>I</b>
<b>Pre-retrofit activities</b>	Client awareness	Cos	Cos		Cust
	-Deep refurbishment	--	--	Int2	
	-Financial solutions	--	--	PubFun; BA	
	-costs/benefits	--	--	Int2	
	-Information about the process of refurbishment	Int2; Cos	Int2	Int2	
	Client expectations	Cos	--	Cust	
	Verification of project eligibility	Int2	Int2	Cust	Cust
	Building data collection	ThDiag	Int2	Cust	--
	Energy auditing	ThDiag	ThDiag	--	--
	Energy use baseline establishment	ThDiag	ThDiag	--	--
	Building performance assessment	ThDiag	ThDiag	--	--
	Recommendations work	ThDiag	ThDiag	Int2	--
	Energy saving estimation	ThDiag	ThDiag	--	--
	Audit report	ThDiag	Int2	--	Int2
	Client review and explanation of the audit report	Int2	Int2	--	Cust
	Draw up estimates	Cust	Int2	Cos	--
	Selection of the craftsmen and their representative	Cust	Int2	Int2	Int2; Cos
	Preparation of the technical records	Cos	Cos	--	--
	Validation of the technical records	Int2	Int2	Cos	--
	Preparation of the financial package	Cos; Cust	Cos	PubFun;	--
Submission for government grant	Cos	Cos	BA; Cust	PubFun	
Submission for zero interest loan	Cos; Cust	Cos	--	BA	
Financial validation	Int2	Int2	--	--	
Declaration of the outdoor work	Cust	Int2	Cos; Cust	RegAg	
			--		
<b>Retrofit activities</b>	Coordination meeting	Int2; Cos; Cust	Int2	--	--
	“Eco advantages” deposit	Int2	Int2	Cos	--
	Implementation	Cos	Cos	--	Cust
	Verification during the work	Int2	Int2	--	Cos
	Demand deposits and grants advances	Cos; Cust	Int2	--	PubFun
	Airtightness testing	ThDiag	Int2	--	Cos
	Commissioning	Int2	Int2	--	Cust; Cos
	Demand for end housing grants	Int2	Int2		PubFun; BA
<b>Post retrofit activities</b>	Post occupancy survey	Int2; Cust	Int2	--	--

Cust: Customer  
 Int2: Initiative 2  
 PubFun: Public funders  
 BA: Bank

Cos: Companies  
 RegAg: Regulatory agencies  
 ThDiag: Thermal diagnostician  
 --: No stakeholder

Appendix III: Summary of the results of the comparative study.

