

Understanding the challenge of housing refurbishment using decision trees

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Abstract

Climate change and oil depletion appear to be among the most important challenges for today and future societies. In order to mitigate possible harmful effects, a radical reduction of energy consumption and greenhouse gas emission is necessary in the so-called developed countries. To achieve a low carbon society, the energy system must be reconsidered in all energy consuming sectors and particularly in existing buildings. Unfortunately, if the final objective is known, the road from policy to action is complex and depends on varying processes and factors of success. A large number of actors are involved in the different steps of housing refurbishment projects. Every actor has a role in this chessboard and each of their actions can influence the target objective. Those influences can work as a lever or a barrier with respect to the final objective and impact the efficiency of the actors' strategy. Understanding the actors' strategy and the dynamics of barriers and levers that draw the road to energy efficiency may help to develop best practices and improve their effectiveness. This paper presents the first results of a survey performed on actors of housing refurbishment in France and on social housing occupants in the Loire Department, France. Using a particular decision tree type, called success tree, the way that could lead to the French energy objective in the building sector will be analyzed. Four types of barriers and levers were identified within refurbishment projects (financial, behavioural, technical and political and normative). This approach may help to better understand the project dynamics that will be necessary to take up the challenge of energy efficiency in this sector.

Introduction

After almost 150 years of fossil fuel consumption, the conclusions are clear: the overall utilization of fossil fuels, especially in developed countries, has depleted the world's oil reserves [ALEKLETT, 2010] and has dramatic consequences on the natural climate equilibrium. Today, the pursued objectives must be very ambitious to mitigate climate change. As a matter of fact, the Intergovernmental Panel on Climate Change (IPCC) states that, to limit the vulnerability of ecosystems and human beings, the lowest and "acceptable" global warming must not increase more than 2 °C [IPCC, 2007]. To keep the effects of climate change under this "acceptable" limit, the atmospheric greenhouse gas concentrations (CO₂-equivalent) need to be stabilized at a value of 450 ppm. In simple terms, this objective means dividing by two the world mean production of greenhouse gases by 2050 or, for developed countries, dividing by a factor of four [GT FACTEUR 4, 2006].

Recently (August 2009), the French government, with the promulgation of Law n°2009-967, has established a scheme of actions which aims to respond to this environmental challenge. The struggle against climate change is claimed to be a priority of this law: "The French government confirms the division by four of greenhouse gases emission between 1990 and 2050 by reducing by 3 % every year its production of greenhouse gas" [Law 967, 2009]. While this document brings change, it is only the legislative aspect of a global political movement started with the Kyoto Protocol and confirmed by successive plans. Unfortunately, theoretical objectives do not necessarily lead to tangible results. Concrete and strong actions should be applied to the main greenhouse gas emitting sectors, the building industry being one of them. Effective measures and huge transformations are needed to reach the objective of the Factor 4 program and mitigate climate

change. The building sector is the most critical for at least four causes. First, it represents a huge potential for saving energy; secondly, transformation of building is the most prolific sector in terms of CO₂ decrease per invested Euros [IPCC, 2007]; and thirdly, the long use life of each building intensifies the consequences of a wrong design. Besides, reciprocally, consequences of climate change may also affect future comfort and energy use in buildings.

In 2008, in France, the existing residential building sector accounts for more than 43 % (69,4Mtep) of the final energy consumption (all use) [CEREN, 2008] and 19 % (99 MtCO₂e) of the country's total greenhouse gas emissions [CITEPA, 2010]. Their increases were respectively of 20 % and 11 % since 1990. Attaining the Factor 4 objective does not mean only constructing new low-energy buildings, but also resolving the biggest challenge of refurbishment for existing buildings. Indeed, more than half of the 33 millions of French residential buildings have been constructed before the first thermal regulations came into effect in 1975. Nowadays, existing thermal renovation techniques could reduce the average primary energy consumption from 240 kWh/m²/year (heating and hot sanitary water) of primary energy to 60 kWh/m²/year [SIDLER, 2007], which means dividing by four the energy consumption of more than 17 millions of residential buildings. Is that possible? In fact, some researches in Europe tend to prove it is [BALARAS and al, 2005]. In some cases, global actions like insulation or new heating systems are suggested as solutions. Unfortunately, the sector of existing buildings presents several peculiarities that make it particularly complex, so theoretical global solutions cannot be applied in the field. Indeed, buildings are very complex engineering systems that were often built at a time when saving energy was not the first priority. Moreover, this poor tradition of energy efficiency must deal with several actors from planning (land planning, architects, engineers, economist, etc.) to use of building (tenants), who do not always have the same goals and perceptions of the target objective [RYGHAUG, 2008].

We begin this paper by presenting the different groups of actors that have been interviewed to define the principal events that can have an influence on the performance (energy consumption and green house gas emissions) of a renovation project. Secondly, we will display the success tree of renovation projects, built using the result of a survey performed on actors of housing refurbishment and social housing occupants. Finally, some of the numerous barriers and levers that can be met by building actors and can influence Factor 4 in this sector will be presented.

Methods

In a refurbishment project, many actors influence the objective. Their knowledge of the building sector represents a big potential to determine the major barriers and levers during a project and elements that must be taken into account.

The first step of this study consisted in the creation of three kinds of studies. The first one is a semi-directive survey for the professional actor of housing refurbishment. The questionnaire for this survey was prepared to obtain subjective responses from the respondents on various questions, which can be summarized in three sentences: What is for you the

main action to decrease the energy consumption of heating in existent building? To apply this or those actions, have you met any difficulties (barriers)? In that case, what are the solutions (levers) suggested to resolve these barriers? Fourteen actors of the building sector have been interviewed, which represents 17 hours of discussion. The second study aimed at analyzing the "Envirobot-mediterranée" forum. Envirobot is a participative forum of building actors which regroups 143 members. All the discussions of the forum transferred by email have been studied for two years (from October 2008 to December 2010). More than 700 emails (totalling around 3,500 discussions) have been treated and all references to the three precedent questions have been notified and classified. Even if these two studies were rich in term of actors and knowledge, one actor missed: tenants. That is why a third study was developed for tenants of social housing buildings in the Loire Department. The survey was conducted in 2009 on 114 tenants who lived in buildings with a project of refurbishment. Twenty questions focusing on thermal comfort and perception of the renovation project have been used to identify the acceptance of the project and the possible change of behaviours in terms of indoor temperature.

Subsequently, using actors' answers to the first question of the survey, we have identified the action plan by using a success tree. The success tree method is an approach developed in 1987 [MODARRES et al, 1987]. It is a logical approach which consists of a synthetic representation of all the combined events which in certain conditions produce a determined event. Success tree is an 'a priori' study of a system. The starting point is a wish event and the method aims to develop and use knowledge of all intermediate events to identify the ways that can lead to success. A top down representation is used to develop a success tree. The top level of the tree consists of a single summit event. All the other levels represent intermediate events that produce the summit event and are connected with logical gates, such as "AND" and "OR". At the bottom of the tree, elementary events are the boundaries of the systems and thus they cannot be decomposed. Building a success tree is about answering the question: "What are sequences which can produce this success event?" [MORTUREUX, 2008].

The sequences can be modified by some barriers which impact the probability of realization of the events of the success tree. The answers to the second question of the survey presented above led to the classification of those barriers into four categories:

- Behavioural barriers are actions influenced by social representations or a definite behaviour;
- Technical barriers are linked to the capacity of intervention of an actor;
- Financial barrier are linked to the capacity of investment of an actor;
- Political and normative barriers are set in a legal field, through obligations and standards.

This paper presents the success tree corresponding to the action plan of actors and one example of each kind of barriers. The choice of this example is subjective, as all these examples were quoted by numerous actors.

Results and analysis

THE ACTION PLAN OF ACTORS

The subjective answers of the first question help to identify the main events and actions that must be applied in a refurbishment project. All the actors converge to an identical goal to increase the performance of the building and, consequently, decrease the consumption and greenhouse gas emissions of heating. The first strategy suggested by some actors is to develop sufficiency. Sufficiency (or to be more precise consumption efficiency) consists for the actor to reduce wastefulness by rational individual behaviour and societal choices: "it answers the actual need to base our future on less compulsive overconsumption, more sustainable and fairer energy needs" [SALOMON et al, 2005]. With respect to heating consumption, the actors of the building sector suggest two actions. The first one consists in decreasing the average temperature of housing to around 19 °C. The second action may focus on the reduction of space heating in terms of square meter per person. Numerous actors refer to these two actions with this interrogation: "how can we reduce the total consumption and emissions of building if the temperature and total space heating increase every year?" The second strategy which arises from the first question of the survey of professional actors is an increase in technology efficiency. Efficiency aims at decreasing the loss of energy during conception and utilization of a working system. In term of heating, three actions have been developed by the actors: decreased loss from the building structure, increased efficiency of the heating system and choice of an energy source with less loss through transformation and transport. It is interesting to see that no actor suggested increasing the use of solar gains to reduce energy consumption. This absence can be explained by two reasons: to increase solar gains for new buildings, architects and heat engineers can play with the orientation of the building and the total surface of windows which collects the energy of the sun. However, in existent buildings, changing orientation is impossible and the creation of new windows appears to be very difficult or very expensive for all interviewed actors.

References to sufficiency and efficiency by most of the actors can be explained by the influence of the NegaWatt approach which has known an important diffusion. This approach was developed by an association of more than 110 experts involved in energy saving and renewable energy. For this association, the best energy is the one that is not used. This potential named NegaWatt could be exploited by an approach based on three actions: energy sufficiency, energy efficiency and use of renewable energy [SALOMON et al, 2005] (Figure 1). The strategy of sufficiency and efficiency combined with the associated actions can be seen as one of success paths to achieve the objective of Factor 4 in the building sector.

THE SUCCESS TREE

One way to formalize this path is to use a representation based on a decision tree analysis, more specifically on a success tree. The representation of the actors' action plan into a success tree is illustrated in Figure 2. In the success tree, we have integrated the influence of the different actions suggested by actors on the three types of energy: primary, final and useful energy.

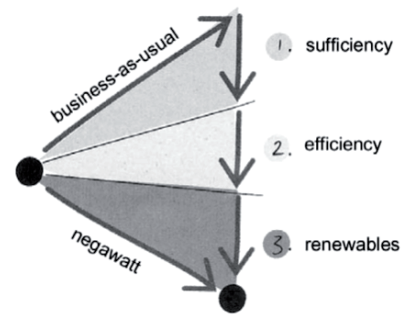


Figure 1. Presentation of the 3 steps of the NegaWatt approach [SALOMON et al, 2005].

- Primary energy is the first form of the directly supplied energy in nature: wood, coal, natural gas, oil, wind, solar radiation, hydraulic power, geothermic, etc. It is not always directly usable and is subject to transformations (for example, refining of oil or combustion of coal to produce electricity);
- Final energy is the energy delivered to the consumers to be converted into useful energy (for example: electricity, gas oil, domestic fuel, etc.);
- Useful energy is the energy available to the consumer, after transformation by his equipment (such as boilers, electric convectors or electric bulbs). The difference between final energy and useful energy is due to the efficiency of the system.

The success tree sketched here describes the main actions influencing the main objective: it can thus be considered as a theoretical efficiency action plan. However, as mentioned earlier, an action is dependent on the presence of barriers and levers. In a success tree, barriers are elements that limit the benefit brought by an action. In some cases, those barriers can be lifted by levers, developed at different scales by actors of the system. To identify those barriers, we have used the answers to the second question and the survey of tenants.

THE BARRIERS OF ACTION

What are the barriers of actions? This simple question asked to building actors received numerous answers. Around thirty barriers have been identified during the survey. Those barriers can be classified into four categories: financial, behavioural, technical and political and normative barriers, as described earlier.

Behavioural barrier

One of the main barriers indicated by the actors is the difficulty to reduce the heating temperature of housing to the French regulatory temperature of 19 °C. In our survey, 61 % of tenants define their ideal temperature as superior or equal to 20 °C during day (Figure 3). However, increasing the temperature to create a better thermal comfort is not harmless. Each degree above 19 °C increases the total heating consumption by about 10 % [SORRELL, 2008]. Worst, the efficiency of buildings have consequences on the wished temperature. In fact, the average ideal temperature indicated by French owners and tenants is 20 °C in old buildings and 21 °C for

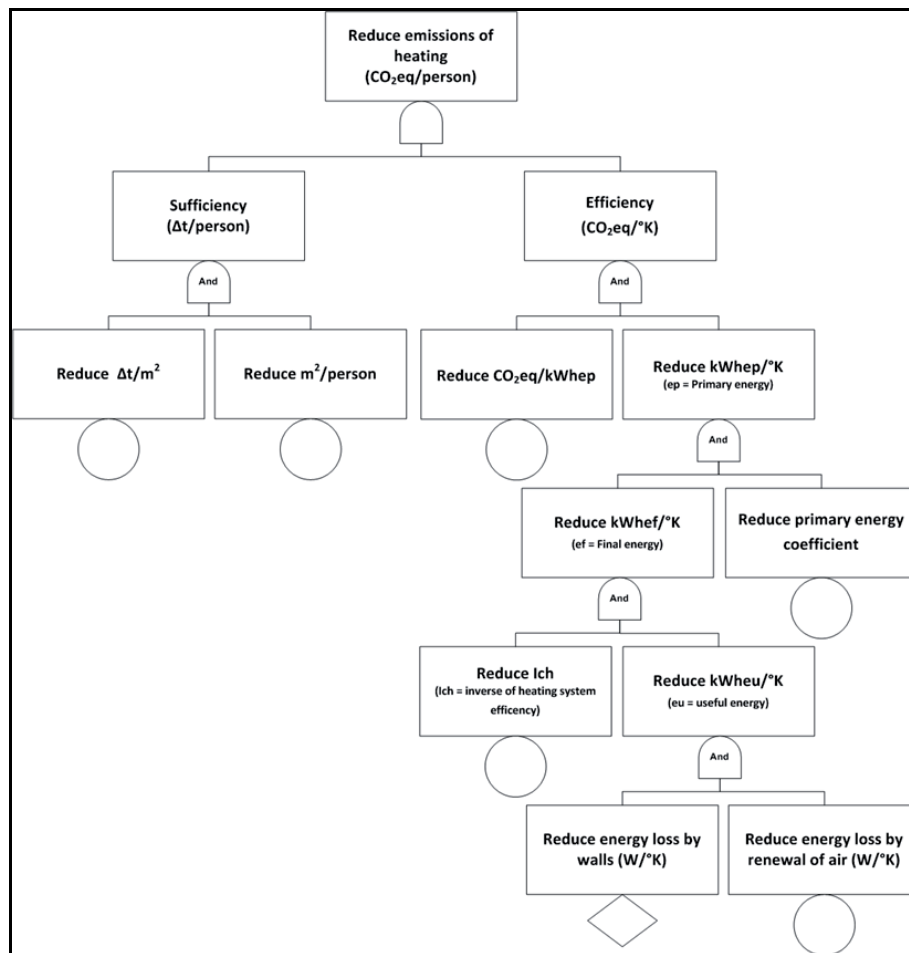


Figure 2. Overview of efficiency and sufficiency strategies using success tree representation.

new buildings which have new technologies and some studies show that this temperature could reach 22 °C [DUJIN, 2010]. This change of behavior with the use of new system produces a so-called rebound effect. The rebound effect, also known as the Khazzoom-Brookes Postulate, was originally discussed by Daniel Khazzoom and Leonard Brookes in the 1980s. This postulate claims that every improvement on energy saving is followed by an increase of energy demand which produces a rebound effect and partially offsets the decrease of energy by efficient technologies [SANTORO, 2009]: “changes in technology have the potential to change consumers’ preferences, alter social institutions, and rearrange the organization of production” [GREENING et al, 2000]. To limit this rebound effect produced by the increase in temperature, the French government developed information campaigns to promote a house temperature of 19 °C. However, for the actors this “moral injunction” is bound to meet with failure for three reasons. The first one is simple, to change the temperature of housing, the tenants must have knowledge of this temperature. However, our survey shows that 61 % of tenants have no idea of the temperature indicated by their thermostat during the day and 57 % during the night (Figure 4). Also, even when an answer is actually given, it is sometimes wrong. The second reason is a resistance to change in temperatures. 60 % of tenants have no intention to reduce their temperature and this resistance increases when the ideal temperature of ten-

ants increases (Figure 5). Thirdly, analytical determination and interpretation of thermal comfort by the calculation of predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) fixed the ideal temperature in housing between 20 to 24 °C [ROULET, 2008]. This calculation shows that for 90 % of people with a metabolism activity of 1.2 Met (reading, working at a desk, watching TV) and clothed with a pullover, under-sweater, trousers and shoes (1.0 Clo) the ideal temperature is 22 °C (Figure 6), far from this one suggested by the information campaign.

To develop sufficiency for heating temperatures and to circumvent the three reasons of failure studied above, some solutions (levers) have been identified by the actors. One of these solutions consists in recreating a zonation of space heating. In fact, since the apparition of central heating, the technology tends to maintain a stable thermal state in time and a thermal balance in space: however, this uniformity is not natural and asks for a huge quantity of energy [HESCHONG, 1981]. Recreating a zonation of space heating is not opposite to good thermal comfort. In a practical view, it may consist of heating to 22 °C the principal part of an apartment (living room, dining room) and to 17 °C the part which are not occupied during the day (bedrooms or bathroom). During the night, the average temperature of the living room can decrease closer to 19 °C and punctual increase in bedrooms can be programmed before sleep and wake up. A lower temperature

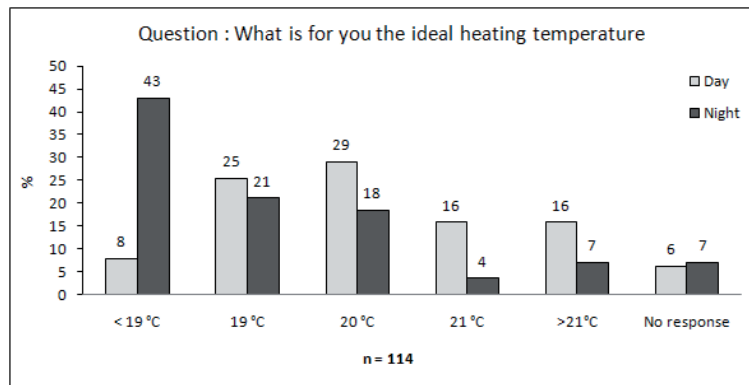


Figure 3. Ideal temperature for housing.

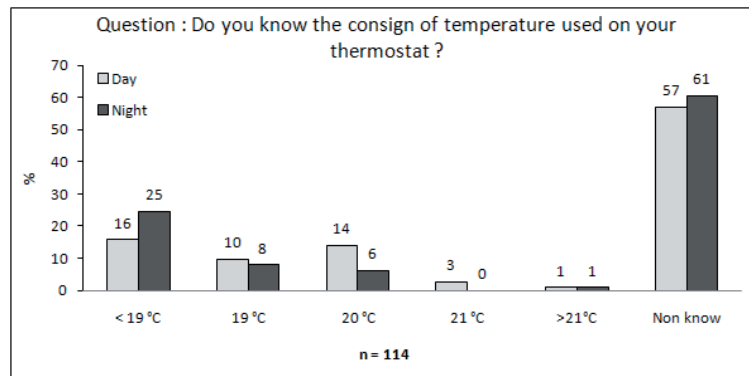


Figure 4. Thermostat consign in housing.

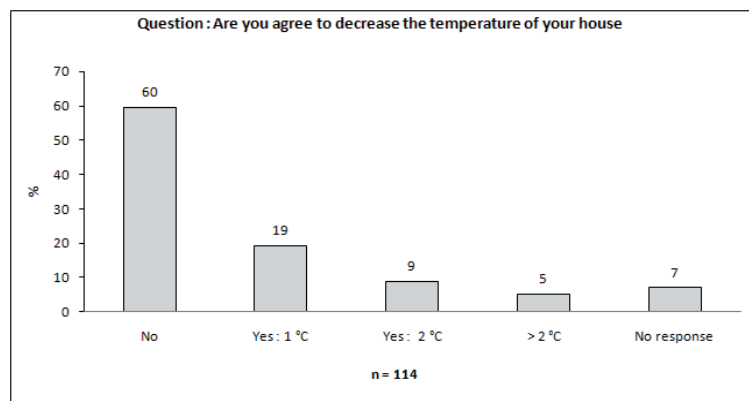


Figure 5. Resistance of temperature change.

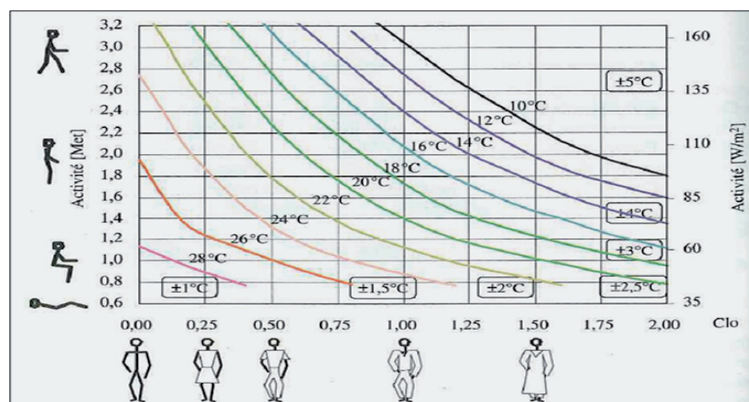


Figure 6. Ideal temperature function of closing and metabolism activity [ROULET, 2008].

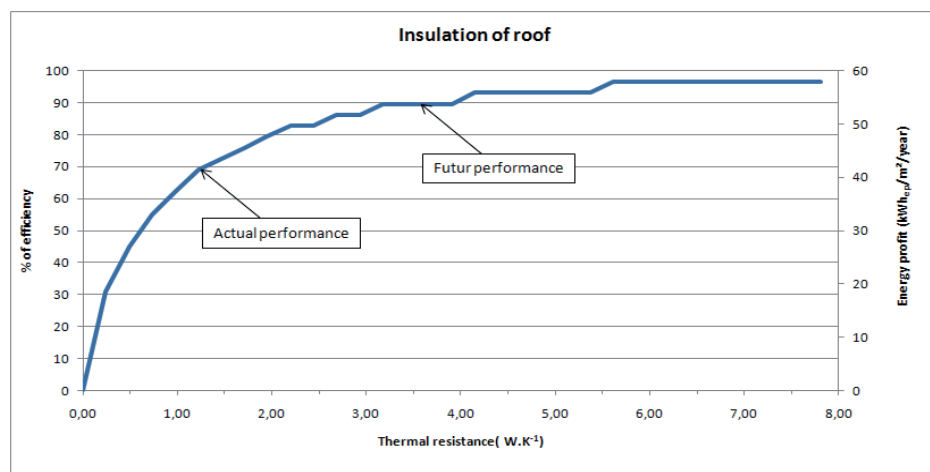


Figure 7. Energy profit of roof insulation in function of thermal resistance.

during the night appears to be possible as we can see in our survey that 43 % of tenants fix their ideal temperature for this period at lower than 19 °C. This scenario of heating zonation has been tested using dynamic thermal simulation on social housing buildings and compared with another scenario of stable thermal area (19 °C). The first results show that there is no significant difference between the two scenarios. The average temperature of each part balanced with the surface is equal to a unique temperature of 19 °C, but the well-being of inhabitants is respected in space and time. The sufficiency strategy proposed by the actors can help to limit the rebound effect, but the influence on the objective of Factor 4 is considered as limited between 10 and 20 % (10 % per degree) by some actors that were interviewed. Therefore, the sufficiency strategy must be coupled with an efficiency strategy. Unfortunately, developing efficiency in building sector is difficult and not free of barriers. The three other kinds of barriers presented in the next sections are focused on the application of efficiency technology.

Political and normative barrier

When we speak about efficiency, the first and biggest barrier defined by the actors of the survey is the absence of political and normative obligations of thermal refurbishment in France. Except for the social housing companies who must renovate the most energy consuming buildings by 2020, all other projects are still on a voluntary basis. However, for the actors of the building sector, without obligation, the objective of Factor 4 is condemned to failure. The actual rate of thermal renovations in France is inferior to the 400,000 recommended every year [Law 967, 2009]. To increase the number of thermal renovations, some actors recommend regulation and obligation to improve the energy efficiency with each sale of housing (every year, around 800,000 flats or houses are sold) [SIDLER, 2007]. But, if this solution is applied one day, it will have to face other regulations that actually limit the efficiency of thermal renovation. In fact, increasing the efficiency of a technology means acting on the building itself and/or the heating system. The decrease in energy loss of buildings is currently obtained by some actions such as insulating roofs, floor slabs, and walls, changing windows, using higher effi-

ciency boilers, optimising the existing hydraulic system, etc. In this paper, we focus, as an example, on normative barriers met by actors for one technology: exterior insulation. Exterior insulation of walls has the potential to decrease from 20 to 35 % the total consumption of a building: it is thus impossible to circumvent for an ambitious project. However, three actual French regulations limit its use. The first one concerns architectural protected areas. For example, in Lyon, the local plan of urbanism in article 3.1 prohibits the use of exterior thermal insulation for buildings with architectural interest. However, in France, these areas represent a major part of city centres. The second normative barrier is the law of 31 March 1999 related to the technical specifications concerning accessibility of the pavement to handicapped people. This law specifies that dimensions necessary to the good displacement of the people are at minimum 70 cm. However, in some towns in France, this law is yet not respected and the development of exterior insulation could reduce the width of the pavement and worsen the situation. Finally, the third regulation on property limit imposes an alignment of buildings in the street. However, an exterior insulation increases the thickness of the wall from 5 to 20 cm depending of materials and techniques: therefore, some projects might not respect this regulation. If no solution to these barriers has been suggested by the actors in the survey, all the respondents think that a political choice must be done between architectural and thermal quality of buildings if a trade-off cannot be found. This example of exterior insulation shows that increasing efficiency is not always possible for specific buildings and situations. Unfortunately, having a thermal renovation project which is not concerned by these political and normative barriers does not guarantee the absence of the two other barriers: technical and financial.

Technical and financial barrier

Financial barriers have been identified as one of the major barriers by the actors [KRAGH, 2011]. In fact, the price of refurbishment projects is difficult to justify with actual economic methods based on short-term payback. To explain this problem, we have chosen to present the example of the social housing of tenants participating in the survey. These housings

have been built in 1950 and are made of 13 small buildings (2 to 3 floors) oriented east-west. In terms of structural specifications, the buildings walls are composed of clinker (35 cm) without insulation. The roof is insulated with 5 cm of mineral wood whereas the basement is insulated with the same thickness of polystyrene. The project suggested by the architect is to reduce the total consumption for heating by insulating walls (exterior insulation) and increasing the thickness of mineral wood to 15 cm in the roof. The total cost is evaluated at more than 7,300 Euros per housing and regulatory simulation estimates a reduction of heating from 226 to 119 kWh_{primary energy}/m²/year (that is approximately 440 Euros less per housing for bills). In this case, the payback per housing is around 17 years (without interest for loans), with the actual price of gas. Who pays for the refurbishment project? Since November 24th, 2009, within the framework of work of improvement of the energy efficiency of housing, a financial backer can ask his tenant to transfer part (maximum 50 %) of the savings in loans to help completion of the work. The tenants see their energy bills dropping and the financial backer does not support only the labor costs. This device is described in theory as “winning/winning”. Unfortunately in reality, achieving 50 % of partition from the tenant is difficult. In fact, this participation is often obtained with an increase of the cost of rent. However, in France, the cost of social housing is limited, and if the maximum cost per square meter is reached, the social landlord has to support alone the total price of the project. In our example, the participation was equal to 23 % of the energy savings, which means a payback of 73 years for the social companies. One of the reasons behind such a long time frame comes from the fact that, as mentioned before, one of the actions is to insulate the roof. However, the roof is already insulated by 5 cm of mineral wood (with thermal resistance of 1.22). Knowing that the major gains are provided by the first centimeters and that saving energy by increasing insulation is not characterized by a linear relation (the last kWh are the most difficult to save), increasing the thickness of insulation by 300 % in our case (thermal resistance of 3.66) improves the efficiency of only 21 % (Figure 7). To lift these financial barriers and not “kill” the energy potential of action, actors suggest two recommendations. The first one consists of “doing well by doing good”: it is better to do just one action to its maximum (insulate roof with 15 or 20 cm of mineral wood), than numerous at a minimum. The second recommendation is economic, as the actual payback is calculated with a stable price of energy. However, even if the fuel/gas price is volatile, a linear regression proves that the price of this kind of energy increases every year. Including this data into payback calculations could be a key aspect to sensitize actors to the ambitious Factor 4 in renovation [KRAGH, 2011].

Conclusion

Factor 4 is an ambitious objective. To reach it in the building sector asks for a mobilization of all the actors of the field. Even if the situation is urgent, we need to take time to define an action plan and identify the paths to success. Drawing pathways that lead to the target objective via decision trees could be a solution to assist actors and formalize actions. Secondly, we must identify barriers and levers that can help to lead to the paths.

Several barriers of action have been identified by the actors as threats to the objective of Factor 4. An overview of barriers defined in this survey leads to think that actors must lift four kinds of barriers: political and normative, behavioral, technical and financial barriers. Their influences on Factor 4 are difficult to quantify, but some actors think that actual dynamics around renovation of buildings are not strong enough to achieve the objective. New levers are suggested to achieve the objective and could be efficient if they are applied. Every actor has a role in this chessboard: to achieve the objective, a common vision among them is needed. The use of a decision tree can contribute to this aim.

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