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A NOVEL MODEL AND TOOL FOR ENERGY RENOVATION PLANNING IN FRENCH RESIDENTIAL BUILDINGS AND DISTRICTS

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ABSTRACT:

Energy renovation of existing buildings is important for energy consumption reduction. In fact, it attracted the interest of governments in several countries for its effectiveness (e.g., 38% consumption reduction by 2020 predicted in France). To achieve such rates, major incentivizing measures were taken by governments to facilitate the funding of energy-oriented renovation projects for final users (e.g., households, communities). Despite all these efforts, a lot of obstacles are yet to be overcome like the lack of interest and involvement of the population, the lack of understanding of the economic equation for renovation, unawareness of governmental aids and support. In fact, most of the population does not fully understand the long-term investment benefits of renovation and look at short term-centered benefits. By taking this into account, the aim of our study is to design, develop and implement a simulation model and decision-making tool to assist final users. The first objective of this tool is to shed the light on the advantages and the benefits of renovation to achieve a maximum awareness. To this end, we studied and highlighted three types of incentives: economical, ecological and comfort. The second objective is related to the technical aspects of the project, where users simulate one or several renovations with different characteristics such as insulation materials, space heater, glazing type. Based on the selected parameters, users will be provided with the cost of renovation works, and achievable yearly savings (energy, money, CO2, etc.). Consequently, the user can make the right decision that suits his needs.

1. INTRODUCTION

The residential building sector consumes 43% of the energy used in France and is responsible for about 22% of Greenhouse gas (GHG) emissions. The energy performance of the French building stock is well below the most UE countries. More precisely, the average consumption (final energy) housing for heating is 138 kWh/m2 against 110 kWh/m2 in the Netherlands, yet with a more rigorous climate. One of the reasons for this consumption level is the age of the French housing stock. Thus, 2/3 of the buildings were constructed before the first oil crisis in 1974. On the one hand no thermal regulation neither thermal insulation for these new buildings were required. As a result, the houses were rarely isolated at build time. In the other hand no performance for heating equipment was identified.

Consequently, in order to improve the energy efficiency the French government promotes the energy renovation of the housing stock. Renovation would divide by 4 to 6, the energy needs of the residential sector. However, in order to start a renovation project, specific diagnosis need to be realized. Technical specifications of each house need to be considered in order to select the most appropriate energy renovation solution. In particular, the diagnosis would take into account, the nature of the thermal envelope (stone house, half-timbered, in-fill walls, etc.), as well as the type of the primary energy used for heat and hot water, or the type of glazing.

This paper illustrates a new simulation model that allows final users (collectivity administrators, house owners, etc.) to evaluate the impact of implementing several energy renovation solutions, mainly thermal insulation (wall, roof, floor and windows), renovation of space heater and ventilation system. This model is assessed on the French renovation policy, to calculate the different renovations contributions (economical, ecological, building characteristics, etc.). At the end, the model will be able to recommend the best renovation solution to the user (single renovation or package of renovations), based on the Net Present Value.

2. RENOVATION POLICY IN FRANCE

Since 2013 France has established an important energy renovation plan for the residential sector. The main objectives of these measures are to promote an efficient energy usage through the implementation of renovation actions. Several research works refer to these programs for instance, in (Baeka, 2012) the authors describe the main barriers facing the energy efficiency improvement in the existing residential buildings. More precisely, they mention important factors such as the absence of relevant information about the energy performances, and the lack of awareness of such measures. The financial aspects and the absence of a regulatory system are also cited as major constraints to the implementation of the improvement measures. Among the European policies that are promoted, the authors focus their interest more on the French policy. The latter involves the following, the financial aid, the building performance certification systems [1] (see section 2.2), and regulation of energy performance of the existing residential buildings, etc. In sections (2.2, 2.1, 2.3), these aspects are fully addressed.

In Denmark, difficulties due to the lack of consideration of the landlords/tenants financial situations are frequently encountered and raise barriers to the achievement of a better energy efficiency. In (Astmarsson et al., 2013) the authors describe the state of play

[1] Certificat de Diagnostic Energétique DPE

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of the deployed measures and the proposed solutions. It is noteworthy to point out that in France similar barriers were overcome thanks to the consideration of the landlord/tenant situation in the proposed financial aids.

In the rest of this paper, we put the emphasis on the French energetic renovation measures and policies. The annual objectives expected after a massive renovation of the existing buildings, as well as a set of priorities, including for instance the fight against fuel poverty (Ademe, March 2016) are part of these policies. Lets introduce hereafter some key elements of the adopted plan.

2.1 Low energy building

On 8th May 2007, a French ministerial order has defined the Low-Energy Building Specification [2]. The order lists the required conditions for a building to obtain the High Energy Efficiency label. Regarding, the residential sector achieving a Low-Energy Building efficiency is strongly related to the climate zone and the altitude in which buildings are located. Previously, the French Ministry of Employment, Social Cohesion and Housing has reported a list of targets and recommendations in Thermal Regulation 2005 for more comfortable and efficient buildings (Ministry, 2005). Thanks to these measures, a target of 15% decrease in the energy bill by 2005 and of 40% by 2020 is expected. A maximal threshold of the primary energy consumption for the heating, cooling, and hot water production is defined according to the area and the geographical coefficient. Geographical zones go from H1 to H3 from the North to the Mediterranean zone. More precisely, the fossil fuel consumption of each building must not exceed 250 kWh (H1), 110 kWh (H2), and 80 kWh (H3) primary/m2/year. In parallel, for the electric heating (including the pump heat) the consumptions must not exceed 250 kWh(H1), 190 kWh(H2), and 130 kWh(H3) $\frac{primaryenergy}{m^2.year}$

2.2 Energy Performance Diagnostic

The energy performance of a building is strongly related to the energy consumption and the gas emission rate. In order to calculate these two values, the French government set up a systematic conventional method named DPE (Energy Performance Diagnosis) [3], (Ministry, 2006b, Ministry, September 2006a). The DPE describes the specification of each building including the newly built. It covers the scope of individual houses as well as the collective buildings. The energy sources, the area, the number of occupants, the different usages, the seasons, and the construction materials are deeply detailed.

In France, the Energy Performance Diagnostic is strongly required before the lease or sale of a residential building. It aims to inform the new landlords or tenants about :

1. The annual quantity of the consumed or estimated primary energy for heating, hot water and cooling, related to the whole building surface or part of it. The measuring unit is the $\frac{kWhPrimaryenergy}{m^2.year}$
2. The amount of emissions of greenhouse gases (GHG) resulting from heating, hot water and cooling, related to the whole building surface or part of it. The measuring unit is $\frac{KgeqCO2}{m^2.year}$,

[2] Batiment Basse Consomation, BBC
[3] Diagnostique de performance énergétique

This information is communicated in form of labels going from the lowest to the highest energy consuming, where A is the lowest consumption. In figure1, we display the French Energy Label scale concerning the annual consumed primary energy.

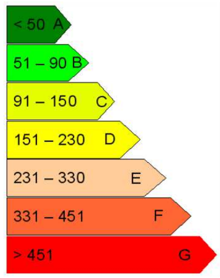

Figure 1. French Energy Label

2.3 Financial aids

The financial aids established by the French government to improve the buildings energy performance are various. Some of these aids are intended for all French people without any condition, others are granted according to a set of conditions. One of the main conditions is the family income, so more important subsidies are granted to low-income households preferentially. The reduction of CO2 is another important condition as an important aid is granted to renovations that will engender a significant gain in CO2. Hereafter, we list the main aids that are proposed by the French government, local authorities and other instances. Governmental websites are dedicated to those who are willing to start renovation projects (Government, 2018)

2.3.1 Tax credit: The CITE is the French Tax Credit for the energetic Transition. It is granted for heating and energy saving works in households. Since 2015 the level of the tax credit has been augmented to 30% of the initial investment concerning eligible works. This tax offers a reduction of the amount of the payable income tax. It entitles households for a payment by the tax authority, even if they pay no income tax. If they are entitled to receive a greater sum than they actually pay in tax, the tax authority will send them a cheque for the balance (Government, 2018)

2.3.2 Energetic premium: It is an aid that can cover up to 20% of the cost of energy renovation works. It can be provided by some organizations such as Total [4], Calculio [5], etc. This premium grant is calculated per square meter depending on the work to be realized.

2.3.3 Energy solidarity pact: It allows to isolate the lost attics. This aid is given by energy suppliers at very competitive and encouraging rates. Energy saving certificates are delivered. The Energy Solidarity Pact is completely independent of the public fundings. [6]

2.3.4 Interest Free 'Eco' Loan: It is an interest free loan dedicated to house-owners and co-owners for renovation works. A 30 000 euros maximum credit is granted. This grant requires

[4] https://www.total.com
[5] https://www.calculeo.fr/
[6] https://www.pacte-energie-solidarite.fr

the selection of professionals that are labelled Environment guaranteed to realize the renovation project. No specific conditions on income in determining the eligibility for the loan are mentioned. A selection of possible renovation works is presented. At least one or two renovation actions are required to benefit from the loan (Ministry, 2018).

2.3.5 The Live Better Program is proposed by the French National Housing Agency (ANAH): The financial support of the Environmental Solidarity Aid (ESA) (Government, 2018) is granted for buildings that are less than 15 years old. For example, in 2016, the ESA for houseowners has been set to 10% of the total amount of energy renovation works. An aid from French Housing Improvement Agency for spending (with limit of 20 000 €) related to improvement works. The amount of the funding varies according to household resources (35% for households with modest resources, 50% for households with very modest resources). In the case of heavy works to rehabilitate an unworthy or very deteriorated housing, the cap of eligible works is 50 000 €and the amount of the ANAH aid is 50% of the amount of the works regardless of the household income. Finally, the Fundings for Thermal Renovation 7 correspond to 10% of the work cost and is capped and modulated according to household income. For example, it is 2000 €for very modest incomes and 1600 €for modest ones.

3. METHODOLOGY

In this section, we present the methodology we adopt. During our work, we have combined field measurements, computer simulations and financial calculations. They are described hereafter.

3.1 Studied building and field measurements

In France, the residential buildings account for 44% of energy consumption where the main source of energy consumption is heating. Moreover the principal channel of energy loss is the building envelope knowing that 25% to 30% of heat loss is done through the roof and the attic, 20% to 25% by walls and 7% to 10% by floor (Figure 2) (Ademe, March 2016)).

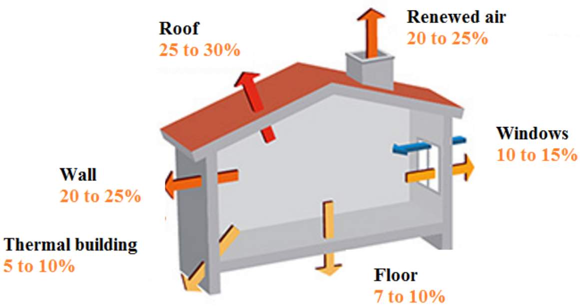

Figure 2. Medium energy loss for houses built before 1974

Consequently, the main priority in energy renovation is to start working on solutions to limit building heating needs and keep cool in summer. These works concern at the first position thermal insulation of the building envelope (walls, roof, floor and windows), that allows to reduce the heat transmission through the thermal envelope. At the second position, it concerns space heaters and ventilation systems that allow to reduce significantly energy consumption. Hence, in our study we focus on residential buildings taking into account their characteristics (building year, area, envelope properties, primary energy for heating, space heater, yearly energy consumption, etc.). To do this, the ground footprint are defined in JSON source which is loaded via a http call. More specifically, we used GeoJSON as a format to encode the geographic data structures. In the same time Buildings are added as a layer on the ESRI map (Esri, 2017). This have been described as a Multi-polygon geometry with the real coordinates. Then, the statistic data are collected from the French National Institute of Statistics and Economical Studies (INSEE) (Insee, 2016). While information concerning heat transmission coefficient of the buildings envelope, costs of insulation materials and space heater, thermal conductivity of insulations material are obtained thanks to the statistical studies done by French Environment Agency and Energy Management (ADEME) (Ademe, July 2015) and the ministry of Employment Social Cohesion and Housing.

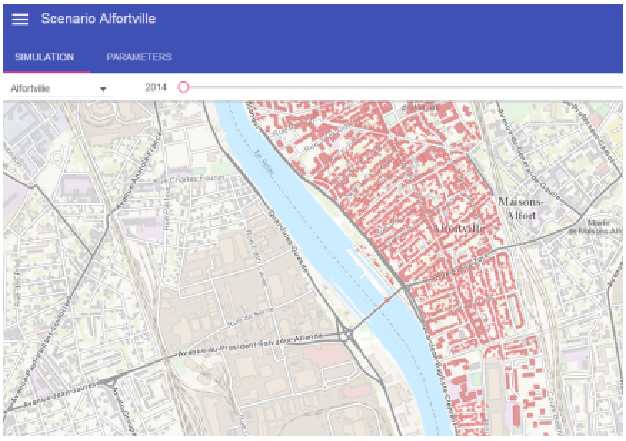

Figure 3. Screenshot of Alfortyville city on ISRI map

In our case, we based on data concerning Alfortville City in France. This city contains 19 656 main residences built from 1919 to 2011 (Insee, 2016). The graph in Figure 4 shows the distribution according to the building year and type. We observe a significant percentage of buildings constructed before the establishment of the thermal regulations (between 1946 and 1970). Hence, our choice for Alfortville City, that allows to test several use cases using our renovation model.

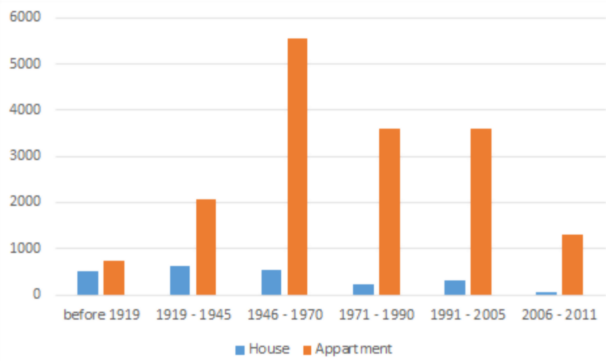

Figure 4. Alfortville residential buildings according to its type and construction year

3.2 Computer simulation

To simulate the contributions of energy renovation we propose a new model implemented using the COSMO modeling language.

This language allows to build complex systems which aims to study the consequences of combining (possibly multi-level) interacting entities, or, conversely, to explain an emerging pattern in an apparently unified system, whose behavior cannot be simply inferred from the behavior of its components (CosmoTech, 2017a). Then our energy renovation model is integrated to the Smart Energy Planning platform (CosmoTech, 2017b) in order to evaluate the contribution of energy renovations before adapting photo-voltaic technology or installing a heat network in a city. This platform enables final users (collectivity administrators, house owners, etc.) to model, simulate, and optimize urban energy infrastructure plans holistically and over a long period of time (over several years).

3.3 Financial calculations

To measure the profit of the energy renovation measurements, our model is based on the Net Present Value (NPV) which is calculated by subtracting the present values (PV) of cash outflows (including initial costs) from the present values of cash inflows over a period of time. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively (Thiers, 2009). The NPV is calculated as follows

$$NPV = \sum_{i=1}^{i=N} \frac{G_i - S_i}{1 + a^i} - I$$

G_i = annual gain; S_i = annual spending; a = discount rate that depends on year and country; N = life time; I = initial investment.

4. DESCRIPTION OF A NEW ENERGY RENOVATION MODEL

To reduce the energy consumption of a building (individual or collective), several types of energy renovations works are taken into account, either by single renovation (one type at a time, e.g. wall insulation, roof insulation, renovation heating, etc.) or by package (at least two types of renovation works). The single renovations concern:

- **Envelope insulation**: it consists of wall, roof, floor or windows insulation
- **Space heater renovation**:it consists of changing just the space heater or changing the space heater with the primary energy type
- **Ventilation system renovation**: it consists of changing the ventilation system

4.1 Energy renovation model synthesis

Our model can be applied in renovation of houses or community ownership. We model each city (City) as being composed of several neighborhoods (Area). Each neighborhood is composed of several buildings.

At the beginning of the simulation, the end-user can configure several types of energy renovations. According to the single energy renovation type that he/she wants to test, he/she can choose the insulation material type and its thickness or the new space heater with its primary energy used and its efficiency, etc. Then the building analyzes the energy renovations one by one. According to the building characteristics (building year, surface, thermal envelope resistances, space heater type, etc.) and the energy renovations features being analyzed (insulation material characteristics, new space heater features, etc.), the renovation contributions are computed (energy annual gain, the gain in money, GHG gain, new thermal resistance in the case of insulation, the lifetime of the renovation, the government or other financial aids, the initial cost including materials and manpower, investment ”the cost of renovation after aids”, the payback and Net Present value). Then, the building analyzes all possible combinations of two or more single renovations in form of packages. Knowing that a package must not contain two renovations of the same type, for example, it should contain only one wall renovation work.

From all available packages and single renovations, our system proposes the best one based on Net Present Value (NPV), with a payback not exceeding the lifetime renovation.

4.2 The main classes

The following figure shows the main class of our model

4.2.1 Building: It can be an individual house or a collective building. Each building has several characteristics

- Building year: represents the year at which the construction is completed,
- Area: it represent the useful area of the building in m^2. In France we talk about Carrez law (loi Carrez)[7]
- Environment Class:it represents the energy consumption of one square meter of a building in one year, it is expressed in $\frac{kWh}{m2.year}$.
- Department: it represents the name or number of the Area department
- Roof: it represents the roof characteristics such as building materials, its thickness in m, and thermal resistance
- Wall: it represents the walls characteristics such as building materials, its thickness in m, and thermal resistance
- Floor: it represents the floor characteristics such as building materials, its thickness in m, and thermal resistance
- Roof Surface: it's the roof surface of this building in m^2
- Windows: it represents the characteristics of window such as surface in m^2 and glazing type (single, double or triple)

4.2.2 Local Equipment: represents all equipment used in the building to meet the needs of residents, including heating, hot water, ventilation, kitchen, etc. In our model we are interested, rather, in heating and ventilation system hence the distinction of two subclasses

- Ventilation System: it consists of ventilation system material (Natural ventilation, double flow ventilation, etc.)
- Space Heater: it consists of the device used for heating and/or hot water such as boilers with its type (simple, condensing, automatic) and the primary energy that it uses (fuel, gas, wood), electric radiant heating or heating pump, etc.

[7] https://en.wikipedia.org/wiki/Loi_Carrez

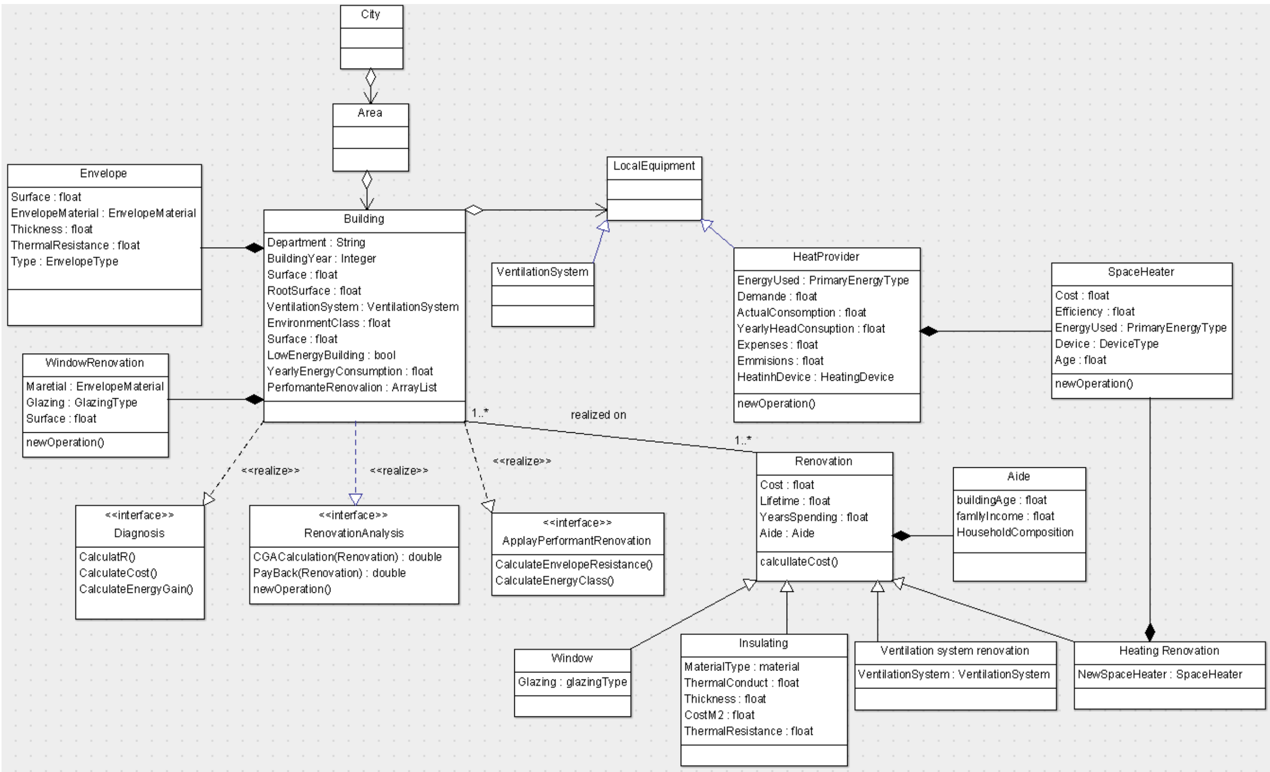

Figure 5. UML diagram of our energy renovation model

4.2.3 Renovation:

Describes the characteristics of a renovation such as life time, type. A renovation can be applied on one or several buildings. As we identify many types of renovation, we define several subclasses with different characteristics:

1. Insulation: it represents the characteristics of the insulating material used, such as the type (polystyrene, roche wool, glass wool, etc.), the cost for one square meter, the thermal conductivity and thickness. The cost and thermal conductivity of materials are static data, related to the country and the current year. In our case, we collect data related to France from (Ademe, July 2015)
2. Space heater: it represent the characteristics of the potential new space heater with its type (classical gas boiler, condensing gas boiler, heating pump, etc.), efficiency, cost and primary energy used,
3. Years spending: it represents the material maintenance cost,
4. Window: its represent the characteristics of the potential new windows with the glazing type (Double Glazing, Triple Glazing),
5. Ventilation system: it represents the characteristics of the potential new ventilation system such as its type (natural ventilation, dual-flow ventilation, etc.).

4.2.4 Financial aids:

It covers the different grants provided by the government, local authorities, energy suppliers in order to facilitate the implementation of energy renovation projects. These aids can be proposed for each renovation by our system, or can be parameterized by the final user to see its impacts on the initial investment. Its principal attributes are :

- Aid Rate: is the fixed percentage for all renovation type concerning the tax rate,
- Aid Value: is the value of the aid when it is not expressed in percentage (for example aids concerning space heater),
- Aide Conditions: for example, building age, family incomes, family compositions, etc.

4.3 Principal features

Our model takes as input several data concerning the buildings characteristics, renovation characteristics and parameters. And it returns as output a recommendation for an efficient renovation or package with its different contributions (energetic, economic and personal comfort)

4.3.1 Renovation Diagnosis:

It represents the first step of the system process. It takes as input all the proposed renovations for a building or several ones in an area. Each building is an autonomous model-based agent that can analyze these renovations, which are configured automatically by the system or manually by the end-user. Then the diagnosis process is realized as follow, according to the renovation type.

- If the renovation concerns the thermal envelope insulation (roof, walls, floor), the building computes:
  1. The thermal resistance R of the envelope:
     - If R is known, this one is used ,
     - Else, if the envelope material type is known, the building recovers its thermal conductivity λ, then it calculates the R using the envelope thickness. Knowing that $R = \frac{Thickness}{\lambda}$.

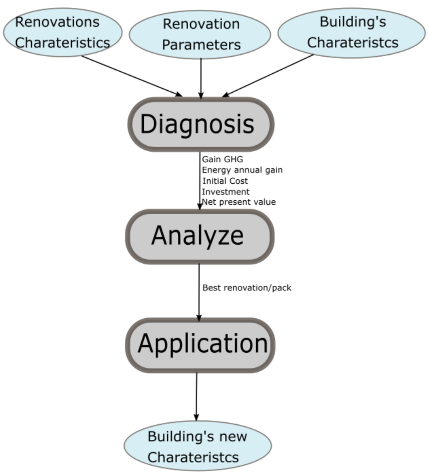

Figure 6. Features step of our renovation model

– Else the heat transmission coefficient (U) is used, it depends on construction year of the building. Knowing that $R = \frac{1}{U}$. The U values change from century to another.

2. The renovation cost, according to the cost of one square meter of the insulating material used in this renovation, and the thermal envelope surface
3. The annual consumption according to its energy class and surface
4. Energy annual gain representing the difference between the quantity of energy required to maintain the room temperature (AnnualEnergy) before and after energy renovation. Knowing that according to (**?**)

$$EAG = \frac{TS * DU * DD * 24 * 1000}{SHE}$$

EAG: Energy Annual Gain; TS: Thermal envelope surface; DU: DeltaU; DD: Degree Day; SHE: Space Heater Efficiency

5. The annual gain which represents the gain in money, it is equal to the product of the annual energy gain and the unit price of the primary energy used for heating.
6. Annual spending corresponding to those given at the instantiation of the renovation
7. The annual GHG gain, which is the product of annual energy gain and GHG Rate

- If the renovation is the heating one, the building calculates the annual energy gain, which is the difference between the primary energy consumed by the household and the new primary energy requirement using the new space heater. And, it computes the GHG gain basing on primary energy, then it calculates the energy premium and annual spending

4.3.2 Renovations Analysis:

It represents the second step of the system process. Where the building browse all the renovations and packages, and based on their Net Present Value (NPV) (Thiers, 2009), it selects the most efficient renovations or package, the one with the highest Net Present Value (NPV) and with payback not exceeding the life time.

4.3.3 Apply Renovation:

after selecting the most efficient renovation or package, the building applies it, and when this concerns:

- thermal envelope insulation, the building updates the thermal resistance of this envelop.
- heating system renovation, the building replaces the old space heater by the new one
- ventilation system renovation, the building replaces the old ventilation system by the new one
- then the building calculates its new energy class

5. SOME SCENARIOS TEST AND VALIDATION

To test our model, we are based on data of an are in Alfortville City (See 3.1). We choose in this paper to show how our tool recommends the homeowners to choose the best renovation project while meeting their budget. Knowing that our model proposes simulation over several years, the energy renovation works performance can be done over several years (several steps) according to different reasons, such as, user budget, payback is greater than life time, energy performance gain, etc.

Firstly, we show the impact of some single energy renovation concerning the same building (Table 4). Secondly, we show the contribution on different packages on one building. At the end, we show the results of the application of our model by scaling-up to an area. In the last scenario, we consider an area with eight buildings. In 5.1. we display the played scenarios and the obtained results.

In the last scenario, we have an area with eight buildings as follows:

Table 1. Studied buildings

Name	Construction years	Area (m^2)	Number of floor	Primary energy used	Energy Class $\frac{kwh}{year*m^2}$
Building1	1947	90	1	Electric	460
Building2	1947	58	1	Gas	430
Building3	1974	90	2	Gas	290
Building4	1970	110	2	Gas	390
Building5	1971	110	2	Electric	490
Building6	1970	45	1	Electric	390
Building7	1967	58	1	Electric	350
Building8	1971	110	2	Fuel	410

And for renovations, we proposed the following:

Table 2. Proposed insulations

Name	Material Type	Thickness (m)
Roof1	Hemp wool	0.7
Roof2	Recycled textiles	0.7
Roof3	Polyurethane Foam	0.7
Wall1	Expanded Polystyrene	0.5
Wall2	Polyurethane Foam	0.5

Table 3. Proposed heating renovations

Name	Space heat	Cost	Efficiency	Energy Used
Heat1	Condensing Gas Boiler	4000	1.05	Gas
Heat2	Electric Radiant Heating	1700	0.4	ELECTRICITY
Heat3	Condensing Fuel Boiler	5500	1.05	FUEL

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5.1 Obtained results

Table 4. Influence of single energy renovation measures

Energy-renovation measures	Energy Class $\frac{kwh}{year*m^2}$	Annual consumption $\frac{kwh}{year}$	Investment (€)	Financial aids (€)	CO2 Gain
Use case: Building 1	430 (G)				
Envelope insulation					
Roof1	295 (E)	17110	2268	497	492
Roof2	290(F)	16820	6331	768	500
Roof3	290 (F)	16240	5428	903,5	497
Wall1	242 (E)	14036	18322	2882	1922
Wall2	248 (E)	14384	3937	1444	1855.79
Space heater renovations					
Heat2	385(F)	22330	1700	370 (F)	99
Heat1	140(C)	8120	4000	600	1560.05

Table 5. Influence of energy renovation packages on one building

Energy-renovation measures	Energy Class $\frac{kwh}{year*m^2}$	Annual consumption $\frac{kwh}{year}$	Investment (€)	Financial aids (€)	CO2 Gain
Use case: Building1	430(G)				
Envelope insulation					
Roof1, Roof2, Roof3, Wall1, Wall2					
Space Heater renovations					
Heat1, Heat2					
Chosen Packages					
At the first time: Roof3, wall2	220 (D)	12760	24654	3440	2420
At the second time: Heat2	110 (C)	6380	4000	6000	760

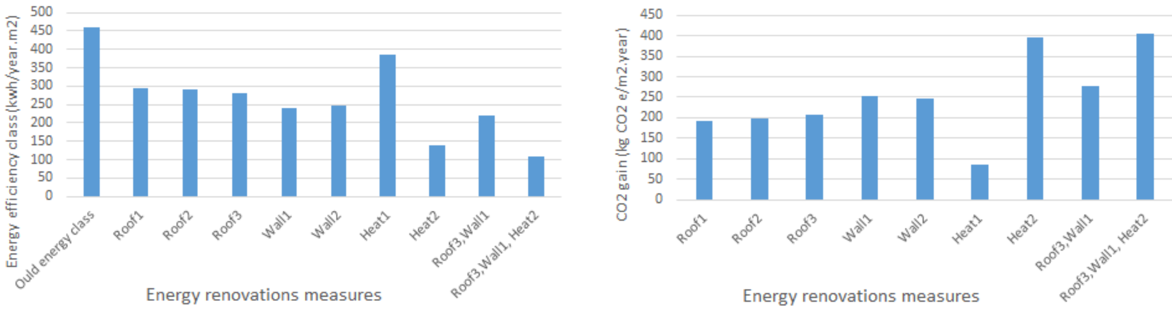

Figure 7. Influence of energy renovation measures on energy efficiency class and CO2 emissions on a building

Table 6. Influence of energy renovation on an Area

	Roof1	Roof2	Wall1	Wall2	Heat1	Heat2	Heat3	Old consumption $\frac{Kwh}{year}$	New consumption $\frac{Kwh}{year}$	New energy Class $\frac{Kwh}{year*m^2}$	CO2 Gain
Building1	x		x					41400	20900	146	205
Building2		x		x	x			24940	8500	232	328
Building3		x	x		x			26100	10100	112	160
Building4	x			x	x			42900	11400	104	315
Building5		x	x			x		53900	20800	189	662
Building6	x		x		x			17500	7300	162	205
Building7		x		x				20300	10200	176	202
Building8		x	x				x	45100	21500	196	4720
Area	-	-	-	-	-	-	-	227090	110700	-	6779

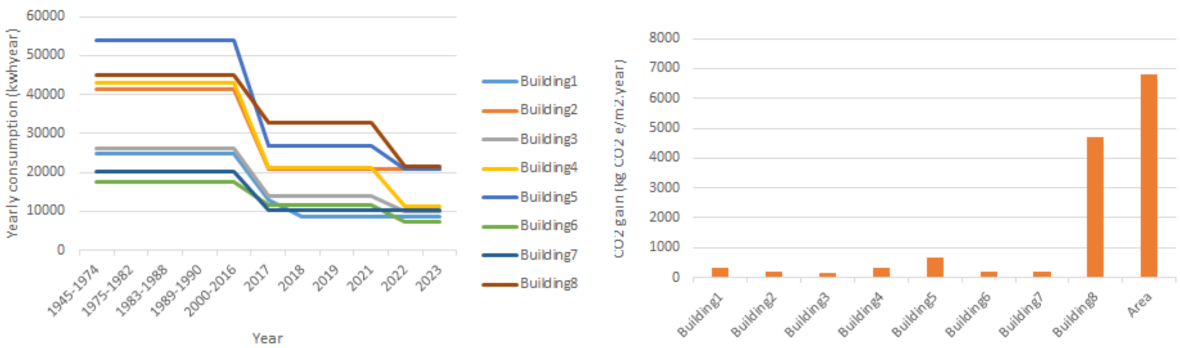

Figure 8. Influence of energy renovation packages on yearly energy consumption and CO2 emissions on an Area

5.2 Results discussion

Our tool allows the user to compare the results of several energy renovations types or several materials for the same type of renovation.

As shown in Table 4 and Figure 7, the contribution of the energy renovation mainly depends on the renovation type (insulation, space heater,etc.). More specifically, it depends on the type of insulation materials and its thickness, or on the space heater type and its primary energy used. We noticed that changing from electricity as primary energy to gas shifts the energy efficiency of the building from class G (460 $\frac{kwh}{year.m^2}$) to class C (140 $\frac{kwh}{year.m^2}$). Furthermore, we observe that combining several renovation types leads to significant energy savings and consequently to CO2 emissions reduction as shown in Table 5 and Figure 7).

We can note that in heating renovations, changing the primary energy use for heating seems to be very important (such as changing from electricity to gas). Moreover, the most efficient space heater is the most profitable one in terms of energy consumption. Regarding insulation, the choice of materials is very important, because some insulation materials are profitable comparing to others despite their high cost.

With regard to renovation packages, we notice that the renovation model recommends the best combination of single renovations to get the best package. Consequently, the building can shift from energy-intensive to a low-energy building by just choosing the best combination of single renovations.

Table 6 and Figure 8 show the results of energy renovation in one area. The table shows that the result for each building depends on proposed single renovations. Generally, the renovations must be performed separately in two steps: first by considering the insulation, then by considering the renovation of space heater. However, doing all renovations in the same package and at the same time could be not profitable basing on the Net Present Value and payback. Accordingly, our renovation model proposes the improvement works in two main steps.

6. CONCLUSION AND PERSPECTIVES

Improving the energy performance of a building is an important operation. It improves the personal comfort, increases the buildings heritage value, and decreases the energy consumption and green-house gas emissions. In order to achieve these goals, the French government is studying the measures to be taken in order to decrease the average consumption of residential buildings from 260 $\frac{kwh}{m2.an}$ to 160 $\frac{kwh}{m2.an}$ in the residential sector. Buildings renovation is one of the best solutions to apply in order to achieve a better energy efficiency. Actually, it divides by 4 to 6, the energy needs. In order to encourage final users to realize renovation operations in their depreciated buildings, several governing policies and aids are proposed.

In this paper, we present a decision-support tool targeting both local collectivities administrators and house owners. We strongly believe that such a tool considerably helps users to simulate the impact of the energy renovations works they intend to perform. Actually, we allow the user to enter the parameters of the renovation project to be done. The renovation activity, the insulation materials, thermal insulation, space heaters or glazing types are set up. Then our system computes the yearly savings that can be made, in addition to this, in case of the simulation of several renovations our system recommends the most important renovation or package. At the end of the simulation the results turn into an illustrated motivating factor.

We assess our model through the implementation of the French governing policies and aids in this field, as well as additional studies on existing energy renovation techniques.

A further work is planned during the next year in order to exploit an experimentation territory in France. We target the Paris-Saclay territory. This work will gather main energy and technological French actors such as The Paris-Saclay Agglomeration community EDF, ENEDIS CosmoTech, Sherpa Engineering, etc.

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