ENERTER: a tool to simulate housing energy consumption

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Abstract
The residential sector is widely considered to have the greatest potential for energy savings. Indeed, it accounts for more than 40% of French energy consumption[1]. The DGUHC[2] commissioned a nationwide study on housing energy consumption with the aim of assessing potential energy savings.

ENERTER is a model developed by Energies Demain to attain the objectives of this study. The model is structured on official database that describe each French residential building. Model enrichment has been carried out to include a structural description of the buildings (architectural type, insulation, wall thickness, etc.). Using those structural parameters, ENERTER can simulate housing energy consumption from town to national scale.

Although the tool can assess energy consumption of housing, for policy makers the real benefit of ENERTER lies in its ability to calculate the energy consumption for each category of the housing stock. As a result, it can show who and where the high consumers are, and can help to define energy efficiency policies based on that information. Indeed, refining knowledge in the residential sector is strategic to define relevant policy frameworks.

As the parameters used to calculate energy consumption are structural, ENERTER can accurately evaluate impacts of rehabilitation programmes in terms of energy savings. That process can also be achieved using energy savings as a starting point. ENERTER calculates how many buildings need to be rehabilitated and how (in terms of evolution of structural parameters) to reach the goal. Thus, ENERTER is a very useful complementary resource to implement efficient energy-saving programmes.

Introduction
Nowadays, experts consider that the residential sector represents the biggest potential for energy savings. Indeed, the residential sector accounts[3] for more than 40% of French energy consumption and releases 20% of national emissions of green house gases (GHG). Acting now on this specific sector seems an obvious way to deal with the steady increase of energy costs as well as the climate change issue. It is urgent to implement effective actions, but how? How to implement both a large scale and efficient action supposed to deliver energy savings, GHG emission reduction, as well as job creation?

Moreover, the task of acting on housing on a large scale is not an easy one. Energy consumption of the residential sector is related to various parameters such as thermal insulation of buildings, heating systems, energy carrier, occupant behaviours, etc.

1. Source : DGEMP (Direction Générale de l'Energie et des Matières Premières) – Observatoire de l'Energie - Centre d'Etudes et de Recherches Economiques sur l'Energie (CEREN).

2. The DGUHC (Direction générale de l'urbanisme de l'habitat et de la construction) is the ministerial delegation in charge of housing and urban planning. It ensures a balanced development of the territory and provides assistance to local authorities in the implementation of their housing policy.

3. Source : DGEMP (Direction Générale de l'Energie et des Matières Premières) – Observatoire de l'Energie - Centre d'Etudes et de Recherches Economiques sur l'Energie (CEREN).

Although accurate energy saving potentials can be determined in diagnosis, this approach is not appropriate when looking at large scales, because of both cost and time issues.

In 2005, the DGUHC commissioned a national scale study on the energy consumption of the residential sector with the aim of assessing the potentials for energy savings. Indeed, refining knowledge about the residential sector is strategic to define relevant policy frameworks and to give incentives to key players in order to achieve these savings.

The study as defined by the DGUHC was meant to answer five key questions:

- What actions can be implemented to improve the energy efficiency of buildings?
- What type of rehabilitation action is the most efficient depending on the type of building?
- What benefits can be expected depending on the type of action and the type of building?
- What are the technical characteristics of the buildings to be refurbished?
- What is the global potential for energy savings depending on various parameters (scope, cost-effectiveness, etc.)?

This study also reflects a critical need to refine knowledge on the French housing stock. Yet, that is also where the main difficulty lies: there is a need for an inventory and a description of the national housing stock but this must also facilitate defining relevant rehabilitation strategies on local levels.

ENERTER is a model developed by Energies Demain[4] to meet these goals. This tool is composed of a database that describes French housings in a discrete way. Each building is recorded and described, enabling calculation of its energy consumption. Because the parameters used to calculate its energy consumption are structural (architectural type of building, construction material, wall thickness, surface, number of occupants, etc.), it enables to link physical actions of rehabilitation to their results in terms of energy savings, and this at every territorial scale.

Thus, ENERTER has two main applications:

- Calculating housing energy consumption at every scale of territory and for numerous parameters (construction date, building type, type of heating system, energy carrier, state of occupation, etc.)
- Making possible evaluation of energy saving potentials at every scale of territory and for all parameters listed above. This application can help prioritize rehabilitation plans on specific targets or define rehabilitation plans to reach a set objective of energy saving.

This document aims to present the key findings of the research that led to the creation of this tool and a practical application of ENERTER.

The first part of the document explains how ENERTER was structured and how the tool calculates housing energy consumption.

The second part illustrates the practical applications of the tool. In addition to the general field of applications, an example of a practical study in which ENERTER has been used, is presented.

ENERTER principles

ENERTER'S GENESIS

The assets of a discrete model

To meet the DGUHC requirements, it has been chosen to develop a model that could simulate the energy consumption patterns of the housing sector in France. Several paths were possible. The main problem was to decide between two options. The first one was going to design a macroscopic model by aggregates. The second option was to go for a discrete approach where each building is described and recorded separately. The second option was chosen because this method has many advantages:

- Being able to explain energy consumption with more details: the disparities between all buildings are taken into account, they are not undermined by the average effect. This affects directly relevancy of the results in terms of energy savings.
- As the characteristics of each building are listed, the data records make possible an assessment of what the impacts of actions implemented on the buildings in the long run are. Thus, it is a dynamic model that can have further applications thanks to data updating.
- Likewise, the building are not ordered a priori in preconceived categories, which leaves more freedom for rearranging data according to what needs to be calculated.

This detailed approach presents many advantages but requires data of much higher quality. This was therefore a critical choice of methodology and was going to make the work more complex and demanding.

The implications of the methodology adopted

Once the choice was made to create a discrete model to describe thoroughly the buildings nationwide, it became necessary to be able to give a technical description of each building according to a series of criteria. These criteria or parameters of description calculation of the need for heating and for energy. This is also meant to allow assessment of how relevant the actions of rehabilitation are. However, this requires data on the structural and technical characteristics of the buildings.

The methodology used to calculate housing energy consumption refers to the standard French national rules[5] of calculation. ENERTER consumption outputs are thus based on calculations and are not real consumption measured in the field.

The data needed to calculate the housing heating consumption are thus:

4. Research consultancy.

5. Agence Française pour la Maîtrise de l'Energie, 1987, Guide de diagnostic thermique.

- Structural description of housing (volume, surface, compactness[6], wall material, wall thickness, type of roof, number of floors, housing type[7], permeability to air, glazed surface)
- Description of the heating system (type of heating system, age, energy carrier, type of ventilation system)
- Housing utilization (housing occupancy[8], number of occupants, etc.)
- Housing geographical situation (altitude, HDD[9], solar radiance)

In addition, in order to be able to define possible actions of rehabilitation, an architectural description of buildings is required: for instance, "Haussmannien[10]" buildings cannot be rehabilitated in the same way as blocks of council flats.

ENERTER'S STRUCTURE

Main structure of ENERTER based on the 1999 national population census

In 1999, an exhaustive census (RGP[11] 99) was done on the whole French territory by the INSEE[12]. The results are freely available at the building scale. Therefore, for each French residential building, the census gives data such as:

- Number of residents, average household size, number of households
- ID number (composed of the building identification and the ID number of the area)
- Town code
- Type (individual house or collective building)
- Occupation state (rented, owned, council housing, main residence, second home)
- Surface of each flat in the concerned building
- Number of floors (for collective buildings)
- Construction date
- Energy carrier for heating
- Heating system characteristics
- Etc.

The descriptive items of the RPG 99 are the only exhaustive data needed for ENERTER that are available at the building scale. As a result, the fundamental structure of the tool was designed to fit the RPG 99 data. Nevertheless, the RPG 99 data are not sufficient to simulate the thermal behaviour of the French housings. An enrichment of the database had to be done concerning: HDD for the area of the considered building, adjacency to other buildings, architectural type, number of floors for individual house, clearance (floor height), roof type, wall thickness and wall material, glazed surface, ventilation system, permeability to air.

The major challenge of the enrichment step was to link the new data to the descriptive items already available from the RPG 99. This is discussed below.

Sharpening of the calculation parameters: the climate effect

HDD is a parameter that characterizes climate harshness compared to a standard temperature. Therefore, it is essential to take HDD into consideration in order to link heating energy consumption to local climate specificities.

A French HDD map was available at a regional scale. Nevertheless, considering that ENERTER is structured at a town scale, some important infra-regional climatic deviations would not have been taken into account. For instance, in a region where there are high variations of altitude, temperatures of towns are likely to deviate significantly and this has an impact on the calculation of housing energy consumption.

As a result, it was necessary to create a French HDD map at a town scale. Considering the altitude deviation between a specific town and the regional meteorological reference town, it is possible to calculate the temperature deviation between the two towns and thus, the HDD difference. This approach led to the map of figure 1.

The adjacency effect

The adjacency effect is essential for heating needs calculations. Indeed, housing that has no direct adjacency to other buildings (e.g. detached house) have more thermal losses than others. This effect has to be taken into account at two different scales: the building one and the dwelling one. Here only the building scale is discussed, as for the dwelling scale, the adjacency effect can be directly treated with the data included in the RPG 99 (as the number of dwellings in each building is known).

Because there was no discrete information about building adjacency available at the national scale, we assumed that housing adjacency was directly related to urban typologies. Considering the uncertainties added by this assumption as well as others stemming from the determination of urban typologies, it was decided to limit the number of urban typologies to six. Their determinations were done using CORINE land cover[13], as presented in figure 2.

The adjacency levels were then translated into a parameter that varies from 0 to 1, according to the urban types.

Architectural typologies

Among the parameters missing in the available housing description, the following ones are related to the architectural typologies of housings: number of floors for individual houses, clearance (floor height), roof type, wall thickness and wall material, glazed surface.

Pascale Graulière, architecture historian, undertook research[14] to describe French architectural typologies based on

6. Related to the number of flat per floor and the number of floors.
7. Individual house or collective house.
8. Main residence, second home.
9. Heating Degree Days; for each day, the number of HDD is determined by the difference between the standard temperature (e.g., 18°C) and the average of the extreme temperatures of the day. It is thus the difference between the standard indoor temperature and the median outdoor temperature.
10. Type of building constructed in cities between 1852 and 1870.
11. Population General Census.
12. Institut National de la Statistique et des Etudes Economiques.
13. Land use database of the IFEN (French Institute of Environment)
14. Pascale Graulière, 2007, Typologie des bâtiments d'habitation existants en

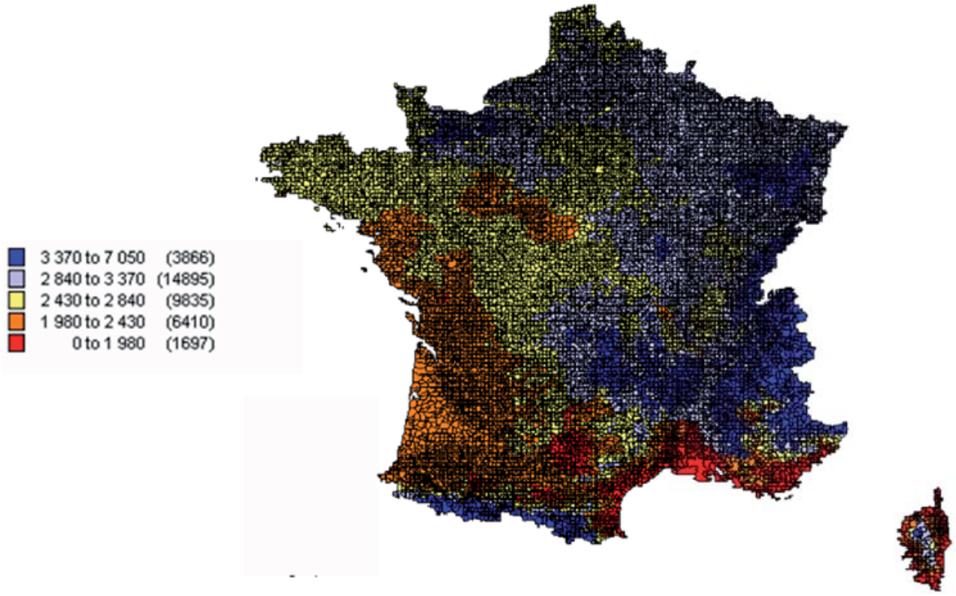

Figure 1. HDD at town level

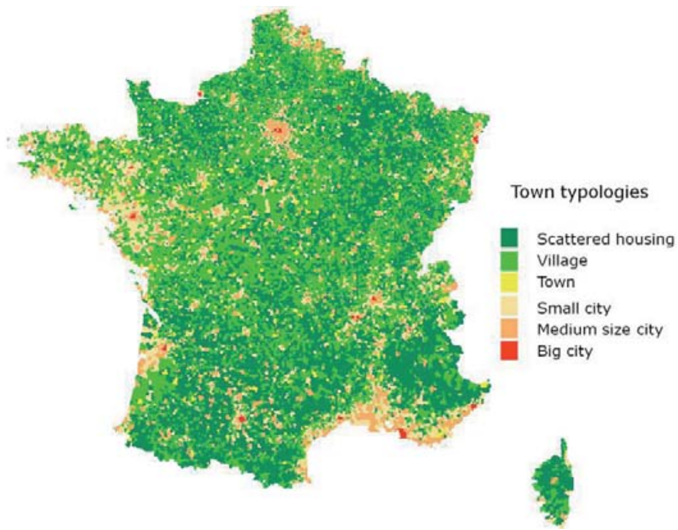

Figure 2. Urban typologies on French territory – Source: CORINNE Land Cover

the data needed for the database. Eventually, she listed 244 typologies with reference to the above parameters. Nevertheless, the most difficult part was then to attribute architectural typologies to buildings.

Architectural typology attribution

The attribution was done using the assumption that architectural typologies are directly related to the type[15] of town, the type of building (individual, collective), the construction date, and the number of floors.

The research carried out by Pascale Graulière made it possible to link all those key parameters to architectural typologies. Nevertheless, for a set of fixed key parameters, several architectural typologies may be possible. Consequently, research was done to determine the probability to find in the field a specific typology for a fixed set of key parameters. It was then chosen to attribute the architectural typology to a building with regards to these key parameters and the corresponding probability.

Construction material allocation

Nevertheless, according to Pascale Graulière, building construction materials and architectural typologies, and thus building thermal characteristics, cannot be directly linked. Indeed, other parameters have to be taken into account:

- Construction materials historically available in the town
- Level of brick utilisation in the town

Therefore, maps were made at the town scale for both parameters. Figures 3 and 4 present maps at different scales for these parameters.

France – rapport de synthèse.

15. See figure 2 (urban typologies)

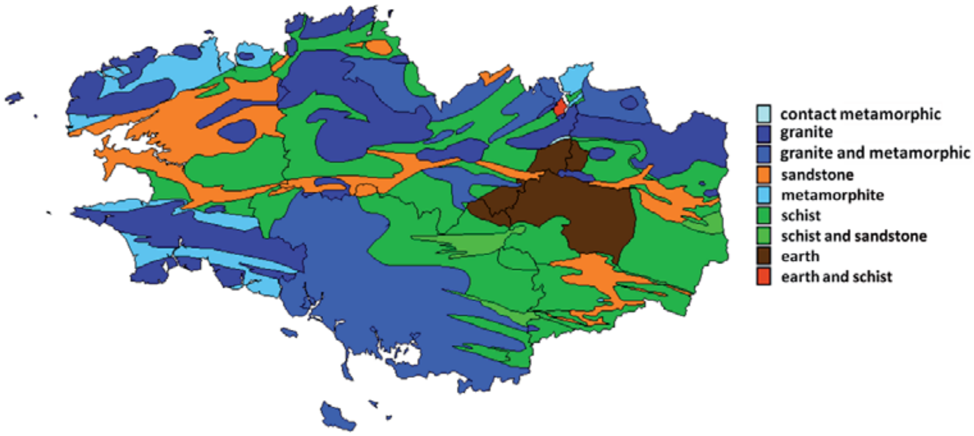

Figure 3. Construction material historically available in the region of Brittany

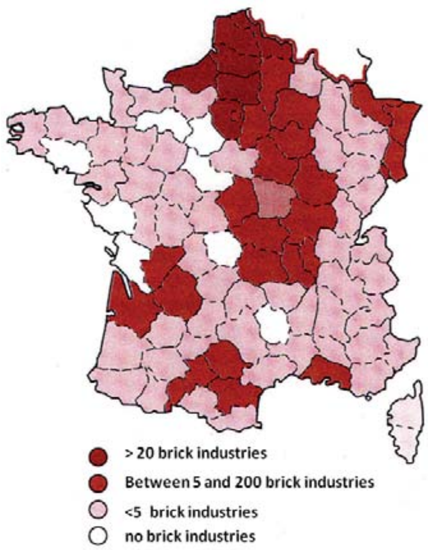

Figure 4. Presence of brick industry in regions in 1952

Knowing the location of the construction material enables us to ascertain the material used in buildings of specific areas. Nevertheless, this process of characterizing the construction material is not relevant for housing constructed after 1915. Indeed, after 1915, assuming that the materials used for construction are only locally available traditional materials might be difficult because of the subsequent development of transport.

For buildings constructed after 1915, construction materials depend only on architectural type, which is in turn related to the type of town. Yet, for the same architectural typology and the same construction date several construction materials may be possible. In this case, for each potential construction material a probability of use has been defined by Pascale Graulière. Table 1[16] is an example for a specific architectural type.

As shown in table 1, a single architectural type may use more than one construction material. An option for calculating the U parameter (thermal transmission) of architectural types which, after inclusion of all parameters (date of construction, location, urban typology, and number of floors) have different possible construction materials could be to simply use the average U of the construction materials. However, it was decided to randomly attribute potential construction materials taking account of the probability they will be found in the field. Indeed, some effects can be hidden by using an average U. For instance, an architectural typology has two potential construction materials that have two very different U values, a high one (poor thermal insulation) and a low one (high thermal insulation). Applying an average U on the architectural typology will hide the fact that some of the buildings of this architectural category have poor thermal insulation and are high energy consumers. On average, the whole architectural type would look as if it had a standard thermal insulation.

Figure 5 summarizes how architectural typologies and construction materials are related.

Rehabilitation

Taking account of housing rehabilitation is essential in the process. Indeed, the methodology used allocates energy performances to buildings with regard to their architectural type and their date of construction. As a result, a building constructed before 1915, likely to have poor thermal insulation, will be considered in 1999 with its initial energy performances. Nevertheless, the building might have been rehabilitated and its energy performances might have changed. Thus, it is essential to take rehabilitation into account if it has an impact on housing energy performance: roof insulation, window, wall insulation, floor insulation. According to the French Energy Observatory, roughly 10%[17] of French housing is concerned by past renovation works that have had an impact on their energy performances. Several studies[18], [19] are available to evaluate what kinds of rehabilitation have been made according to the following parameters: location, architectural type, date of construction.

16. Local stones: Related to the traditional local construction material available

17. Data 2006 from the Observatoire de l'Energie

18. Centre d'Etudes et de Recherches Economiques sur l'Energie (CEREN), 2005, Enquête réhabilitation

19. Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire, Comptes du logement.

Table 1. Construction materials according to architectural type.

Architectural type	Construction date	Urban typology	Construction material	Probability	Wall thickness (cm)	Thermal transmission parameter U ($W.m^{-2}.°K^{-1}$)
Lodge 1	1949-1967	8	local stones	50 %	35	1.6
Lodge 1	1949-1967	8	breezeblock	35 %	20	2.6
Lodge 1	1949-1967	8	local stones + brick lining	15 %	30	2
Lodge 1	1916-1948	6	brick	33 %	30	1.65
Lodge 1	1916-1948	6	concrete	33 %	20	2.7
Lodge 1	1916-1948	6	local stones	33 %	35	1.6

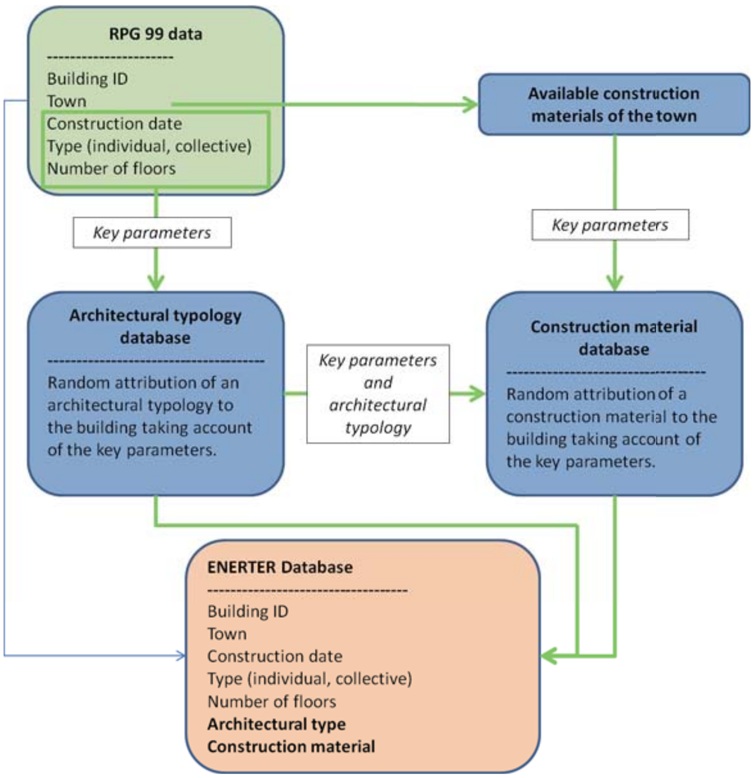

Figure 5. Principle of structural description allocation

Global calculation process of ENERTER

Validity of the results

ENERTER's primary aim is to assess potential to make energy savings. That is why the choice was made to use only computer simulations based on structural data to evaluate French housing consumption. This is the main asset of the tool and also its main weakness. However, when it comes to evaluating energy savings potentials related to rehabilitation, ENERTER is extremely valuable. But of course when it comes to giving a very accurate evaluation of energy consumption, it may deviate from reality.

The version of ENERTER using the 99 RGP data was never calibrated on official energy consumption[20]. Nevertheless, as shown on the figure 9, the comparison between the regional energy consumption calculated with the tool and official energy consumption supports to ENERTER.

Globally, ENERTER results are close to the DGEMPs' estimations. Reassuring as that may be, it does not constitute an absolute validation as the DGEMP uses a similar methodology to evaluate energy consumption.

Comparison with field data were also made. The results are presented later on.

UPDATE OF ENERTER

ENERTER was successfully developed using RGP 99 data. Yet, to be efficient, the tool had to be updated to take account of construction, demolition and rehabilitation of buildings, heating system turnover, and energy carrier changes.

Even if the residential sector has a certain inertia, in order to be relevant, ENERTER has to be updated every five years.

20. Direction Générale de l'Énergie et des Matières Premières (DGEMP), Observatoire de l'Économie de l'Énergie et des Matières Premières, Observatoire de l'Énergie, L'énergie dans les régions.

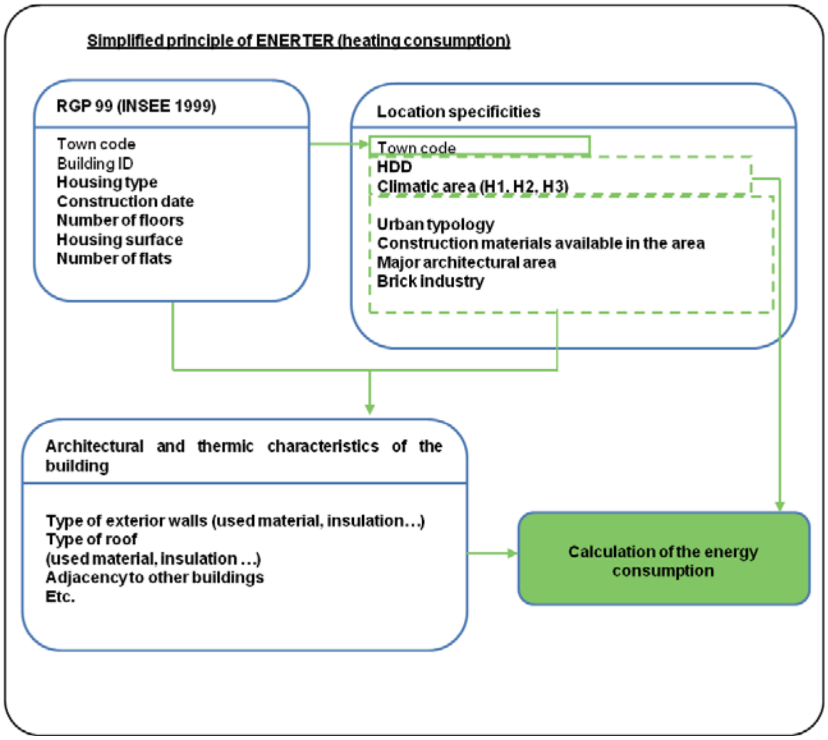

Figure 6. Calculation process of ENERTER

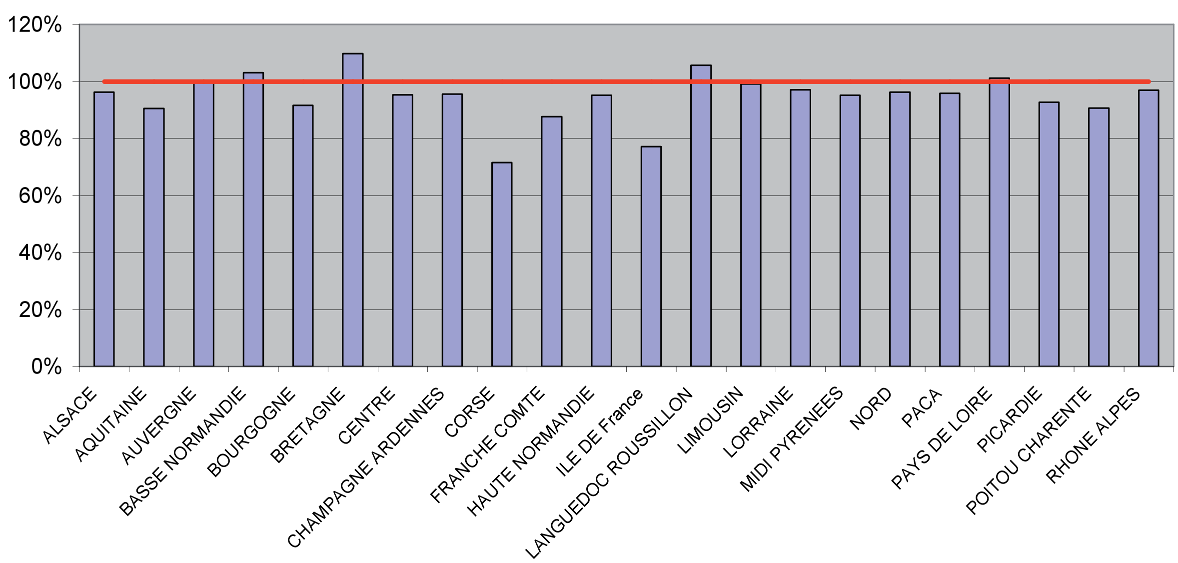

Figure 7. Deviation rate between the regional energy consumption calculated by ENERTER and official consumption from the DGEMP

Housing turnover

Taking into account new constructions can be easily solved by the use of the Sitadel[21] database. This official database contains every operation that requires a building permit: information about location (town scale), surface, number of floors, type of building (individual or collective housing), number of flats (for collective building), etc.

The information provided by Sitadel is sufficient to calculate energy consumption even if there is no information about thermal performance (thermal conductivity). In fact, every new building has to meet the energy requirements defined by the national building code. As a result, it is possible to evaluate energy consumption of new buildings using these requirements.

Because building demolition is also subject to permits, official information about it can be found easily.

21. Système d'information et de traitement automatisé des données élémentaires sur les logements et les locaux (Sitadel), Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire

Rehabilitation

The number of households[22] that implemented energy efficiency actions on their dwelling is detailed in an ADEME[23] - SOFRES survey[24]. It also gives details on the various type of renovation done:

Share of wall rehabilitation in the building renovation as a whole	**25**	%
Wall (indoor insulation)	9	%
Wall (outdoor insulation)	2	%
Roof	10	%
Floor	4	%
Share of window rehabilitation in the building renovation as a whole	**26**	%

This information was used to update the matrix of rehabilitation defined for 1999.

Heating system turnover

The RPG 99 gives the situation about housing heating systems in 1999. This was updated for 2005.

Heating systems are changed for two main reasons: breakdowns or change of energy carrier.

Concerning heating system turnover due to breakdowns, a reconstitution of the age pyramid of systems was done for 1999 using data on heating system sales[25]. By using the average heating period[26] per year on one hand and the heating system lifetimes on the other hand, it was possible to estimate heating system turnover between 1999 and 2005.

Concerning energy substitutions, the main source of information is the National Energy Observatory. They did a study[27] showing the evolution of energy carriers for heating in residential buildings. In addition, an annual survey[28] on about 40 000 randomly chosen houses, containing the same kind of information as the RPG 99, was used.

This information concerning energy substitutions and heating system turnover was synthesised in a matrix that gives the probability for heating system changes. This matrix also takes into account local specificities such as town gas and district heating possibilities.

Calibration

As the process of updating ENERTER required modeling various parameters and more specifically heating system turnover, the assumptions had to be calibrated so that ENERTERs' energy consumption simulations are calibrated on the official regional energy consumption[29] per energy carrier.

COMPARISON WITH FIELD DATA

In 2008, the ADEME commissioned a study on the energy consumption of all buildings in the Picardy Region – north of Paris – at town-level. The objective was to provide ADEME Picardie with a database showing the energy profiles of residential buildings.

This was the opportunity to test ENERTER within the framework of a local-scale study and more specifically to check that the structural data pattern provided by the model matches the reality it is supposed to describe.

In order to see if the distribution of architectural types was correct, we undertook a reality check with the support of ADEME.

Sample

The perimeter defined for the field observation covered a representative sample of local town councils. The sample[30] of approximately 4000 buildings was defined so that the whole range of building types, building ages and the distribution between rural and urban areas were well represented.

Field test

The objectives of the field study were to look at the following parameters:

- Adjacency: isolated or adjacent;
- Construction materials: concrete, brick, limestone, wood timbers and bricks, wood timbers and limestone, breezeblock;
- Type of roof: mansard roof with attic or without attic, roof terrace;
- Type of woodwork: casement window, sliding window, French window.

It is important to mention that the observations were made from the street with no further investigations; so it is important to be careful when using the results. Some buildings were considered to be built in limestone or brick while it may have been only the visible part.

Figures 8 and 9 present the results of this field test for adjacency and construction materials.

Concerning building adjacency, ENERTER results match with the field data quite well.

It is worth mentioning that the category "breezeblock or brick or concrete" refers to new buildings for which the construction material was hidden.

It appears that ENERTER results are globally satisfactory. Yet, inaccuracies relative to the method of field investigation as well as the lack of description of actual architectural typologies[31] may hide some deviations. Although the observed results

22. Household is here defined as the occupants of a house/flat
23. Agence de l'Environnement et de la Maîtrise de l'Energie
24. Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) SOFRES, Maîtrise de l'énergie, bilan 2000, attitudes et comportements des particuliers.
25. DGEC (Direction Générale de l'Energie et du Climat) – ADEME information
26. In relation with heating system type, house occupancy and house type.
27. Observatoire de l'énergie, 2004, 20 ans de chauffage dans les résidences principales en France de 1982 à 2002
28. Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire, Comptes du logement.
29. Direction Générale de l'Énergie et des Matières Premières (DGEMP), Observatoire de l'Économie de l'Énergie et des Matières Premières, Observatoire de l'Énergie, 2006, L'énergie dans les régions.
30. Towns of the sample :Flavy-le-Meldeux, Grandru, Larbroye, Cuts, Noyon, Pont-l'Evêque
31. The less detailed level of description of recent architectural typologies can be explained by the fact that the emergence of building codes enabled to determine building energy consumption without using high precision parameter of thermal transmission.

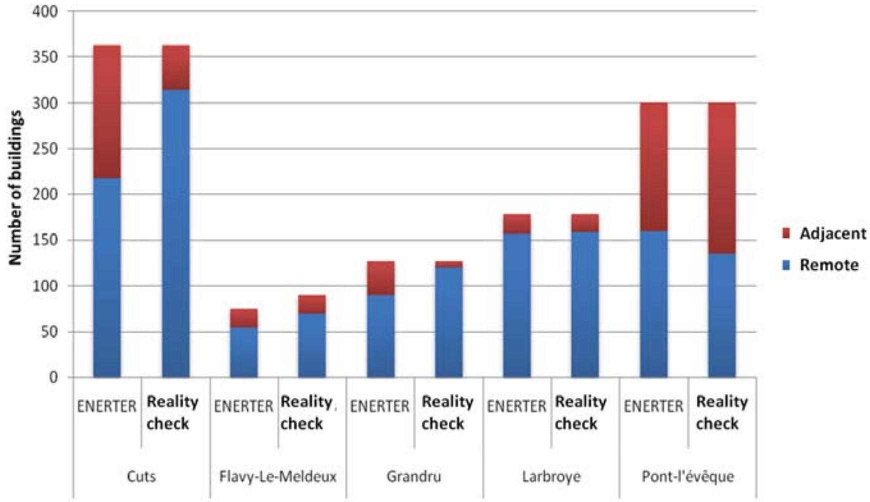

*Figure **8**. Adjacency – Comparison between ENERTER results and investigations in the field for four towns.*

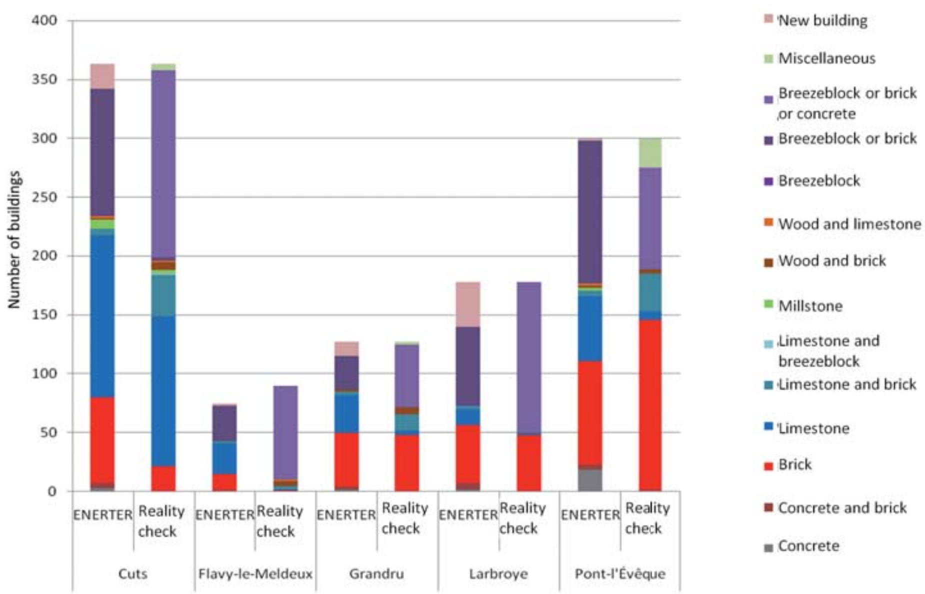

*Figure **9**. Construction material – Comparison between ENERTER results and field data for four towns.*

are encouraging, they also show the need to continue this approach of field-testing to improve ENERTER.

Practical applications

SCOPE OF PRACTICAL APPLICATIONS

Energy consumption assessment

One of the practical applications of ENERTER is energy consumption assessment. Indeed, in France, official energy consumption assessments are only available for a regional or a national scale. Occasionally, they are also made at an infra-regional scale. For local authorities, however, it is still quite difficult to get an idea of what their residential consumption is.

For policy makers, the real benefit of ENERTER is its ability to calculate the energy consumption for each category of the housing stock. As a result, it can show who the high consumers are and can help to define energy efficiency policies based on that information.

Programmes of energy saving and rehabilitation

The most important thing about ENERTER is its ability to calculate potential energy savings.

In fact, ENERTER does not provide rehabilitation recommendations. They have to be defined separately and based on architectural typologies and current state of housing. Once defined, rehabilitation recommendations are translated into structural parameters such as thermal transmission parameters or heating system efficiency. Then, the new parameters are integrated in ENERTER and the tool simulates the new energy consumption of housing. After that, the amount of energy saved can be estimated by comparing energy consumption results with and without the rehabilitation programme. This approach is used to evaluate how relevant rehabilitation programmes are.

That process can also be achieved using energy saving goal as a starting point. ENERTER calculates how many buildings have to be rehabilitated and how (in terms of evolution of housing structural parameters) to reach the goal. Then, the evolution of the structural parameters has to be translated into a practical action of rehabilitation. This approach is likely to be used by local authorities that already have energy saving objectives and need to define rehabilitation programmes to meet them.

Those practical applications of ENERTER have already been implemented with a number of local authorities[32].

Nevertheless, another interesting application of ENERTER is to work on a selected housing type. Indeed, it is possible to assess potential energy savings not only in real territories such as towns, cities, regions, or France, but also in fictitious territories. For instance, it is possible to define a territory composed only of council housing as was done for some studies[33]. In these cases, it enables very accurate work on specific targets such as council housing.

Scenarios of energy efficiency policies

ENERTER can also be used as the basis for dynamic scenarios: by integrating demographic evolution and therefore the need for houses, ENERTER can simulate future energy consumption. Yet, to do so, parameters such as rehabilitation and heating system turnover have to be carefully defined. This approach led to the implementation of a simplified version of ENERTER in SceGES, a tool developed by the MIES[34] to evaluate future regional GHG emissions (2005 to 2030). Scenarios can be implemented in SceGES to evaluate the effect of national environmental policies in comparison with a standard scenario: for instance, for the residential sector, different scenarios of rehabilitation or of thermal regulations on new buildings can be tested.

EXAMPLE OF PRACTICAL APPLICATION

In 2008, GDF Enerbat[35] commissioned a national scale study on the energy consumption of the residential sector. The objectives for GDF Enerbat were two-fold:

- to acquire knowledge about the consumption of the residential sector;
- to assess the potentials for energy savings and their cost.

ENERTER was used for this purpose.

Energy Current state of energy consumption for the residential sector

Figures 10 show some of the results calculated by ENERTER for this study.

As it appears on the figure 10, unitary consumptions due to heating can be very different from a location to another. That is due to the different types of housing, construction date, eating system, and climate harshness.

For instance, the climate effect is obvious on the southeast cost of France where unitary consumptions are low. On the opposite, the centre of France is characterized by high unitary consumptions. Indeed, that is the Massif Central, a mountainous part of the territory. The northeast part of France is characterized by high unitary consumptions. There, housings have poor energy performances because of their architectural type. Paris is quite visible on the map as it has low unitary consumptions. Indeed, urbanized areas have much more collective buildings than rural areas and collective buildings have lower unitary consumption than individual houses.

The map presented here gives a general view. Nevertheless, It has to be studied with all other parameters (type of housing, construction date, total energy consumption, etc.) in order to enables prioritizing geographical areas to act on. In the GDF Enerbat study, that approach have been implemented for every architectural type of housing.

Potential energy savings in relation with different scenarios

The rehabilitation recommendations were produced the research consultancy Tribu Energie for each architectural typology per action (wall insulation, floor insulation, window, ventilation system, heating system) and based on the initial state. Three different scenarios were defined: a cautious one, an aggressive one (best technology available) and a "0% rate loan" one (equivalent to 30 000 Euro per house). The recommendations are composed of technical parameters (system, performance, insulation, etc.) and economic parameters (cost of materials and cost of implementation based on average national costs). The technical parameters were integrated in ENERTER in order to evaluate energy savings of each scenario. In addition, the economic parameters were used to evaluate the cost of each scenario. The following figures show some of the aggregation of the results for all architectural types.

Achieving the reduction by 4 of the housing energy consumption for heating, means investing about 900 billion Euro. That represents roughly 30 000 Euro per dwelling. Nevertheless, scenario cost-effectiveness are not constant as they decrease with energy saving increase. Reassuring as this may be, cutting by 60% housing energy consumption still represents 15 000 Euro per dwelling.

However, those energy saving are only related to technical scenarios of rehabilitation and do not represent an economic reality.

In France the law "Grenelle 1" has defined a target of a 38% reduction in housing energy consumption by 2020. On the basis of several studies[36, 37, 38, 39, 40] on rehabilitation work, it

32. Among others, the local authorities of the town of Montdidier (Pircady Region), of the town of Clichy-la-Garenne (region Ile-de-France), of the département de la Seine-Saint-Denis (93), of the region Bretagne.

33. Paris Habitat (council housing of the city of Paris), council housing of the region Midi-Pyrénées, council housing of the region Rhône-Alpes

34. Mission Interministérielle à l'Effet de Serre (MIES)

35. GDF Enerbat : research department on energy consumption of building of Gaz de France

36. Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) SOFRES, Maîtrise de l'énergie, bilan 2000, attitudes et comportements des particuliers.

37. Observatoire Permanent de l'amélioration Energétique du logement (OPEN) Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), 2007, Analyse 2006 de l'offre et de la demande en matière d'efficacité énergétique dans les logements – note de synthèse.

38. Bérénice Le Fur - Club de l'amélioration de l'habitat (CAH), 2004, Mesurer et comprendre les marchés de l'amélioration de l'habitat.

39. Club de l'amélioration de l'habitat (CAH), 2002, Enquête nationale Logement (ENL) 2001-2002

40. Institut National de la Statistique et des Etudes Economiques (INSEE), Dépense d'acquisition de logements et de travaux.

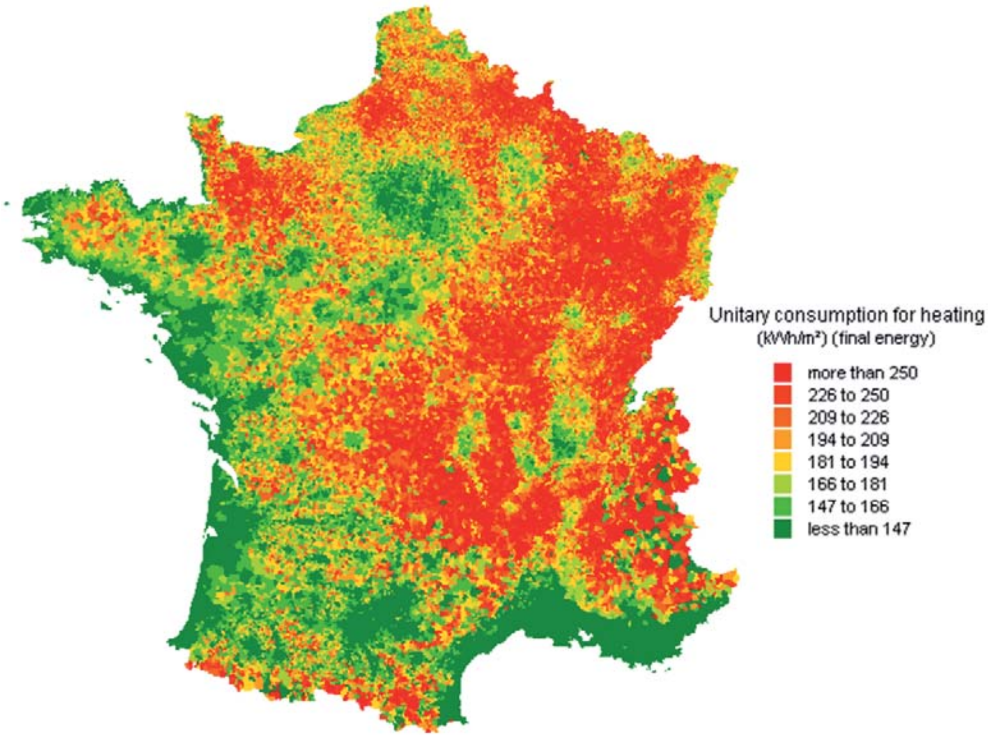

Figure 10. Outputs of ENERTER for the GDF Enerbat study: regional energy consumption per date of construction of housing; unitary consumption per type of house (individual house, collective building)

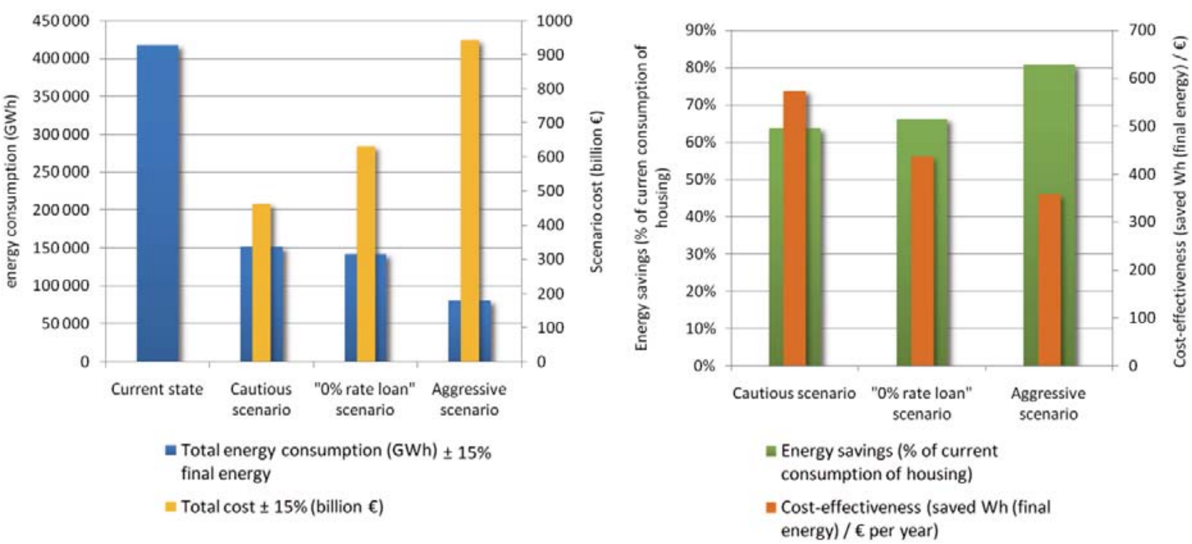

Figure 11. Global results of the GDF Enerbat study – Energy saving, cost, and cost-effectiveness of the scenarios

is possible to evaluate what the impacts of rehabilitation on housing consumptions are and what type of housing are usually rehabilitated. Based on that estimation, a scenario was built to assess the impact in 2020 of the current[41] rate of rehabilitations (50 000 housings a year). In that scenario, energy savings will reach about 1% of the current consumption of housing for heating.

The rehabilitation objective most often advocated is 400 000 rehabilitations per year in addition to the rehabilitation of 800 000 council housings. A second scenario was built to estimate the impact in 2020 of the 400 000 rehabilitations per year. Using that scenario, ENERTER evaluates that energy savings will not exceed 21% of the current consumption of housing for heating. Defining an objective of 38% of energy saving has been evaluated as implying 1 480 000 dwellings rehabilitated per year (between 2009 and 2020) in addition to the rehabilitation of the 800 000 council housings. Consequently, it seems to be urgent to define a national policy to boost rehabilitation in order the reach the objectives define by government for housing energy consumption in 2020.

41. 2005

Conclusion

ENERTER was designed in order to answer questions about the energy consumption of the residential sector and evaluate potential energy savings on town to national scale. The tool was successfully developed on a discrete structure that describes every residential building in France and its energy consumption.

Nevertheless, ENERTER is a mathematical model. Thus, it is not a description of reality although it comes quite close to being one. The main difficulty is that the results, especially regarding architectural typologies, cannot be compared with any other tool's results or any other database. It can only be compared with the reality of the 30 million residential buildings by enquiries in the field.

Research on ENERTER is ongoing in order to fine-tune the results. Some parameters, such as the assumptions concerning rehabilitation and architectural typologies can be improved. As an example, a study on the Brittany Region with the ADEME, currently in progress, aims to improve those parameters in that region.

Nevertheless, ENERTER is already a powerful tool for local authorities and policy-makers in need of efficient energy-saving programmes, thanks especially to its ability to explain energy consumption in considerable detail.

The strength of the tool is its capacity to link a structural description to energy consumption while, at the same time, accounting for the specificities of a particular location. As a result, ENERTER is able to calculate the impact of changes in the structural parameters of housing in terms of energy consumption. As rehabilitation has a direct impact on the structural parameters of buildings, ENERTER can estimate energy savings which result from rehabilitation programmes.

In addition, as ENERTER segments housing per type, studies on specific aspects of the residential sector such as council housing, are greatly facilitated. It also allows consideration of other parameters: for instance, by comparing the energy needs of housing, occupant state (owner, renter), heating system type, social issues involving energy insecurity risks can be highlighted, and rehabilitation programmes prioritized accordingly to address those issues.

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