# PRELUDE Roadmap for Building Renovation: set of rules for renovation actions to optimize building energy performance

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**Abstract**. In the context of climate change and the environmental and energy constraints we face, it is essential to develop methods to encourage the implementation of efficient solutions for building renovation. One of the objectives of the European PRELUDE project [1] is to develop a "Building Renovation Roadmap"(BRR) aimed at facilitating decision-making to foster the most efficient refurbishment actions, the implementation of innovative solutions and the promotion of renewable energy sources in the renovation process of existing buildings. In this context, Estia is working on the development of inference rules that will make it possible. On the basis of a diagnosis such as the Energy Performance Certificate, it will help establishing a list of priority actions. The dynamics that drive this project permit to decrease the subjectivity of a human decisions making scheme. While simulation generates digital technical data, interpretation requires the translation of this data into natural language. The purpose is to automate the translation of the results to provide advice and facilitate decision-making. In medicine, the diagnostic phase is a process by which a disease is identified by its symptoms. Similarly, the idea of the process is to target the faulty elements potentially responsible for poor performance and to propose remedial solutions. The system is based on the development of fuzzy logic rules [2],[3]. This choice was made to be able to manipulate notions of membership with truth levels between 0 and 1, and to deliver messages in a linguistic form, understandable by non-specialist users. For example, if performance is low and parameter x is unfavourable, the algorithm can gives an incentive to improve the parameter such as: "you COULD, SHOULD or MUST change parameter x". Regarding energy performance analysis, the following domains are addressed: heating, domestic hot water, cooling, lighting. Regarding the parameters, the analysis covers the following topics: Characteristics of the building envelope. and of the technical installations (heat production-distribution, ventilation system, electric lighting, etc.). This paper describes the methodology used, lists the fields studied and outlines the expected outcomes of the project.

## 1. Introduction

One of the objectives of the PRELUDE project is to propose ways of reducing the buildings energy consumption while ensuring the comfort of the occupants, which we call Building Renovation Roadmap (BRR)

This implies that, when faced with an existing building, one must be able to qualify the energy performance (consumption), the state of the elements of the envelope (characteristics and level of degradation), the efficiency of the technical installations (technology, adjustments), and to establish a list of actions with priorities for intervention. This includes the possibility to detect malfunctions of the

building either by observing a drift in consumption compared to the objectives, or by reporting complaints from the occupants.
To achieve this objective, we propose a decision process divided into the 5 main steps described in Figure 1 below. The idea is to observe the building status, to detect deviations, to review the potential causes, and to dress a list of actions.

The purpose of this work is to build a set of decision rules based on fuzzy membership functions that allow both deviations and potential causes to be "qualified" and to deliver a list of recommendations in a linguistic form.

As a first approach, we propose to focus the analysis on residential buildings and, more precisely, on collective housing, which represents a considerable stock of buildings in Europe (as an example, this category of building represents about 2/3 of the built area in the State of Geneva).

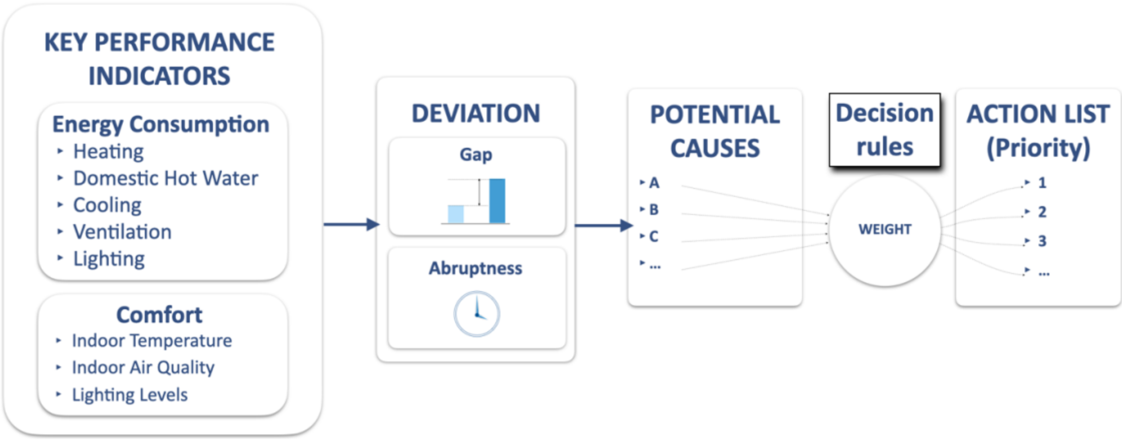


*Figure 1: Simplified representation of the decision-making process.*

## 2. Method

As the final objective of BRR is to provide guidance to improve the performance and comfort of buildings, we have chosen to use a method that delivers recommendations in a linguistic and intuitive form. The goal is to target different building stakeholders involved in the renovation process (building owners, architects, building diagnostics experts).

The interface should facilitate the description of the characteristics of the building and its technical installations, in particular:

- Allow for imprecise parameters to be considered:
  When diagnosing a building, a certain amount of data cannot be understood in any other way than in vague terms.
- Facilitate the description of the problem:
  Working on linguistic concepts allows us to remain as close as possible to the way of thinking of the various actors (diagnosticians, owners, architects, etc.).
- To initiate a process of optimization for the design parameters:
  The purpose is to establish a list of actions with integrated priority levels to facilitate decision-making.

### *2.1. Fuzzy sets, membership functions, linguistic variables*

Fuzzy logic allows to consider values inside non-rigid boundaries. The membership of an element u of a universe U to a subset A takes its values in the interval [0, 1]; it is described by a "membership function". This indicates the "possibility" that the element u belongs to the subset A.
The uncertainty underlying this notion of membership can, in many cases, be represented using linguistic variables, taken from everyday language. A linguistic variable is defined as a variable whose values are

sentences (or parts of sentences) in a natural or artificial language. If "big", "not big", "very big", etc., are values of height, then height is a linguistic variable.
In the following, we show how to qualify the state of a given parameter by assigning it a degree of belonging to one or other of the linguistic categories that describe the properties of that parameter.

For example, the actual heating energy consumption of a given building, can belong to one of the following categories:

- *Very low, Low, Moderate, High, Very high.*

The membership of each of these categories can also be associated with the potential for improvement that can be expressed with the same linguistic form: A "*Very High*" consumption indicates that the potential for improvement is also "*Very High*".

*2.2. Key Performance Indicators qualification: Example of the heating energy consumption*
We propose to qualify the potential for reducing energy consumption of a given building as a function of its position on the energy class scale.  shows the example of Heating demand, where this potential can be qualified as "Very Low" (1), "Low" (2), "Moderate" (3), "High" (4) or "Very High" (5) depending on the energy class of the building.

*Dual membership*
In addition to the fact that it introduces flexibility in the designation of an element, the notion of gradual membership includes, the possibility of "multiple membership". In the example presented in Figure 2, the heating consumption, which is equal the Limit value +140%, is rated as "Moderate" to "High". The truth levels for each of these two statements are 0.22 and 0.78 respectively.

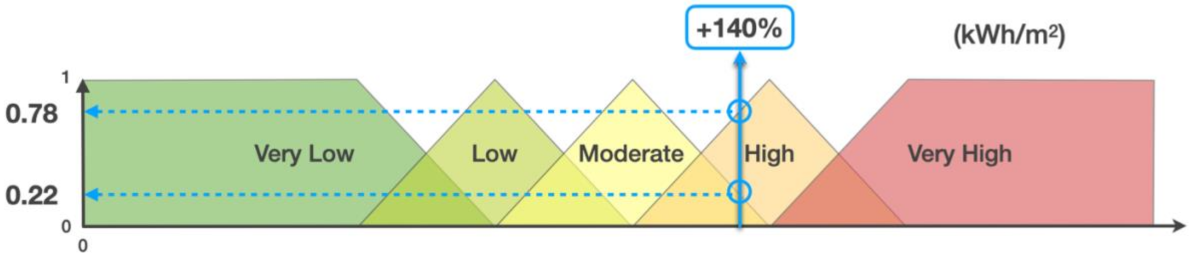


*Figure 2: Example of a building with an annual heating consumption equivalent to 140% of the limit.*

*2.3. Potential causes: Example of the Walls U-Values*
Similarly, each of the parameters that influence the energy consumption should be reviewed to determine its potential for improvement. Thus, in the example shown in Figure 3, the Wall's U-value is broken down into 5 fuzzy subsets.

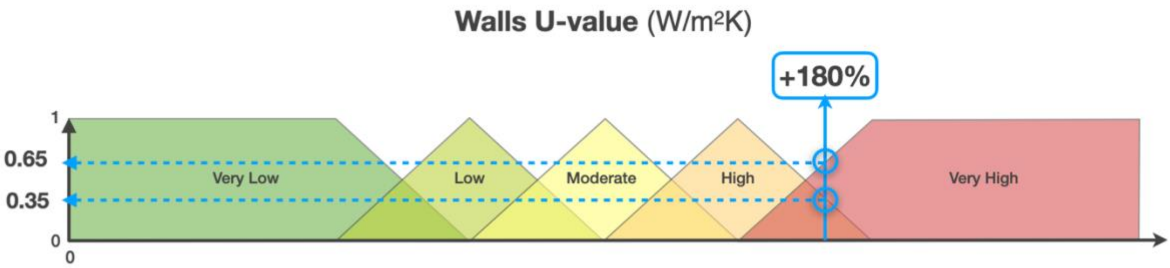


*Figure 3: Fuzzy decomposition of the different classes describing the influence of the Walls' U-value to reduce heating consumption.*

We propose to use the SIA (Swiss Standard) limit values as [4] a basis and to set the thresholds for membership of the various fuzzy subsets for each deviation steps of +50% from this limit value.

## 2.4. *Incentive levels*

Once the potential for consumption improvement has been determined on the one hand, and the potential for improvement of a given parameter on the other, the principle consists in deducing the strength of the incentive level to be delivered to the user.

We propose four distinct levels of prompting, each associated with a verbal injunction:

- Imperative Incentive ➤ You **MUST** (check or modify the parameter)
- Strong Incentive ➤ You **SHOULD** (check or modify the parameter)
- Slight Incentive ➤ You **COULD** (check or modify the parameter)
- None ➤ -

## 2.5. *Aggregation process*

If we take the cases mentioned above (cf. Figure 2 & Figure 3) where energy consumption for heating = 140% of the limit value and U-value of the walls = 180% of the limit value), we have 4 incentives that are simultaneously activated, as shown in Figure 4.

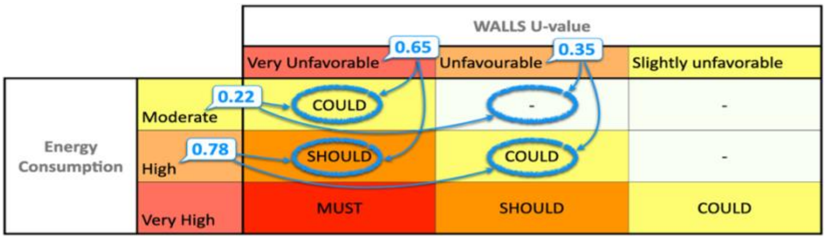


*Figure 4: Determination of the incentive levels to be delivered according to the measured performance on the one hand and the potential for improvement associated with a given parameter on the other.*

We use the minimum implication process, whereby the lowest truth value is retained for each activated rule. Thus, in the case treated here, the levels of truths for each of the combinations are as follows:

$E_{Consumption}$ = Moderate (0.22) / U-value = Very Unfavourable (0.65) ➤ ***COULD*** = Min(0.65,**0.22**)

$E_{Consumption}$ = Moderate (0.22) / U-value = Unfavourable (0.35) ➤ ***NONE*** = Min(**0.22**,0.35)

$E_{Consumption}$ = High (0.78) / U-value = Very Unfavourable (0.65) ➤ ***SHOULD*** = Min(0.78,**0.65**)

$E_{Consumption}$ = High (0.78) / U-value = Unfavourable (0.35) ➤ ***COULD*** = Min(0.78,**0.35**)

When two identical incentive levels are simultaneously activated (in this case the “COULD” level, i.e. Slight incentive), the levels of truths add up. We thus have the following results:

- NONE: 0.22
- COULD: 0.57 (0.22 + 0.35)
- SHOULD: 0.65

The incentive delivered is the one that gets the highest value, so in this case:

*You SHOULD improve the insulation of the walls.*

When all the parameters have been reviewed, the list of recommendations is displayed, according to the incentive levels and the degree of truth of each injunction. This presents a list of actions prioritised according to their presumed importance.

# 3. Considered parameters

At this stage of the project, the parameters mentioned in Table 1 have been characterised with fuzzy membership functions. For the construction of the different membership classes, we relied heavily on recommendations from Swiss practice and standards (e.g. Energo documentation [5]).

| | |
|---|---|
| Building Characteristics | Form Factor |
| | Inertia |
| | Climate related correction (Orientation, Latitude Altitude) |
| | U-values (Roof, Walls, Floor, Windows, Doors, Blind boxes) |
| | g-values (Windows, Shading devices) |
| | Automation (Openings, Shading devices) |
| Heating Syst. Characteristics | Multiple boilers in a row: Switching process |
| | Max. temperature, Large & Small Flame Switching |
| | Heating schedule |
| | Indoor Set point temperatures (Normal & Reduce) |
| | Heating curve (Non-Heating point, Design point) |
| | Heating limits (Day-Night / Winter-Summer Limits) |
| DHW Syst. Characteristics | Maximum DHW Temperature |
| | DHW Large & Small flame Switch-ON & OFF |
| | Circulation pumps: Time Scheduling |
| | Set-Point Temperatures |
| | Temperature Hysteresis |

*Table 1: First list of parameters taken into consideration for the analysis*

The following topics are still under development and will be included in the final version of the Building Renovation Roadmap:

- Lighting
- Ventilation
- Cooling
- Renewable Energy Sources

## 4. Input

The input parameters are divided into the three following categories:

- Main parameters: Mandatory
- Sub-parameters: That make it possible to define the main parameters if they are not know (or no intuitive for the users).
- Advance parameters: Only used and known by experts.

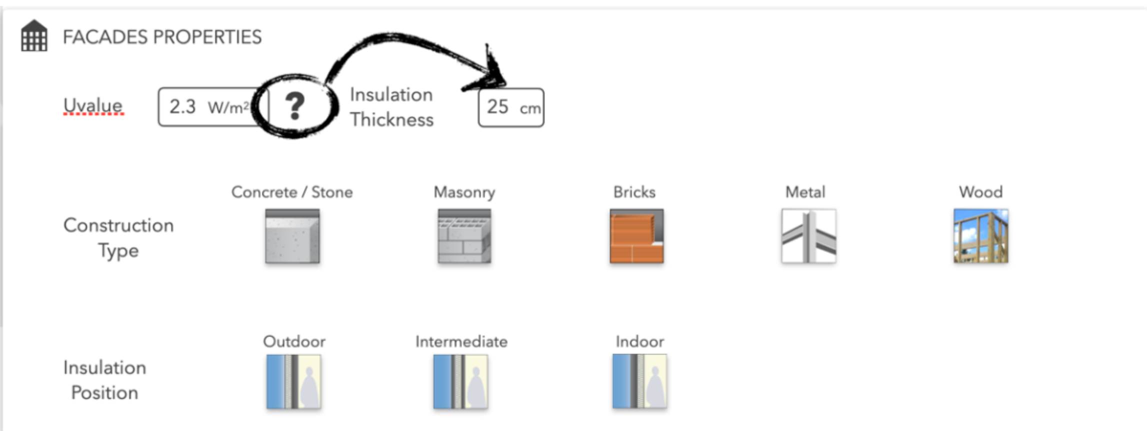


*Figure 5: Example of an input screen to quickly describe the building.*

In the example shown in Figure 5, if the user does not know the U-value of the façade (*Main*), which will happen in most cases, icons allow him to quickly describe his case with *sub-parameters*.

## 5. Output

The results of the diagnosis are presented in the form of a list of incentives with estimated costs for the corresponding works. These costs come from the EPIQR cost database [6].

Since decision-making is highly dependent on the financial capacity of the actors, it is of high important to be able to rely on credible costs for renovation, maintenance and improvement works, which together determine the performance of buildings. The updating of this database and the integration of new technologies are an integral part of the PRELUDE project in which the Building Renovation Roadmap is developed.

The **HEATING** Consumption is **VERY HIGH**

| *List of potential actions* | | *Estimated costs* |
|---|---|---|
| You MUST | ➡ Change the glazings | 26'000 € |
| | ➡ Improve the Ground-Floor insulation | 8'500 € |
| You SHOULD | ➡ Complete the Pipe insulation | 6'000 € |
| You COULD | ➡ Install thermostats on radiators | 2'700 € |

*Figure 6: Example of recommended actions issued from the diagnosis*

## 6. Conclusions

Buildings are very complex objects and few people are in a position to master all the subjects that condition their energy and environmental performance. The BRR as we conceive it aims to synthesise a body of disparate knowledge and to propose concrete actions. The ideal framework in which we wish to position this tool is the moment of the realisation of the energy performance certificate. In concrete terms, the tool, which will be available in the form of a web-app, should make it possible to fill in any missing information and to draw up a list of prioritised actions that will help the actors involved in the renovation process to target the most decisive actions.

## Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 958345 (PRELUDE)

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