The Integrated Renovation Process

case studies detailed report

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February 2014

Table of Contents

Table of Figures

Table of Tables

1. Introduction: The Integrated Renovation Process

The Integrated Renovation Process (IRP) is a user customized methodology based on judiciously selected constructivist and interactive multi-criteria decision making methods (Galiotto, Heiselberg, & Knudstrup, 2014 (expected)). When applied for home renovation, the Integrated Renovation Process for Homes (IRP4homes) supports, informs and reassures homeowners to decide on a sustainable renovation of their home while getting the corresponding associated benefits and therefore a home more adapted to their lifestyles. The IRP4homes also helps the building experts to be more effective for the quantitative analyses and the generation of the renovation scenarios so they get more time for the cost optimisation and the qualitative analysis of the homeowners' needs, wishes and behaviours.

2. Mixed approach for the evaluation of potential renovation scenarios

2.1. Homeowner customized approach

In order to increase the chances that the homeowners makes the right decision, the research for the best solution has not been based on a quantitative optimisation only but rather on a mixed qualitative / quantitative approach in line with the homeowners' personal values and wishes. The approach is constructivist and knowledge is progressively transferred from the building expert to the homeowners while maturating data is collected by the building expert from the homeowners. The iterative process is composed of the following activities: analysis of the profile of the homeowners and diagnosis of the building, identification and selection of the quality and performance criteria and sub-criteria, generation of some renovation scenarios and selection of the most appropriate scenarios, multiple criteria evaluation of the renovation scenarios with the homeowners and the building experts, synthesis and presentation of the results and finally selection of the most favourable renovation scenario and implementation of the measures (see Figure 1).

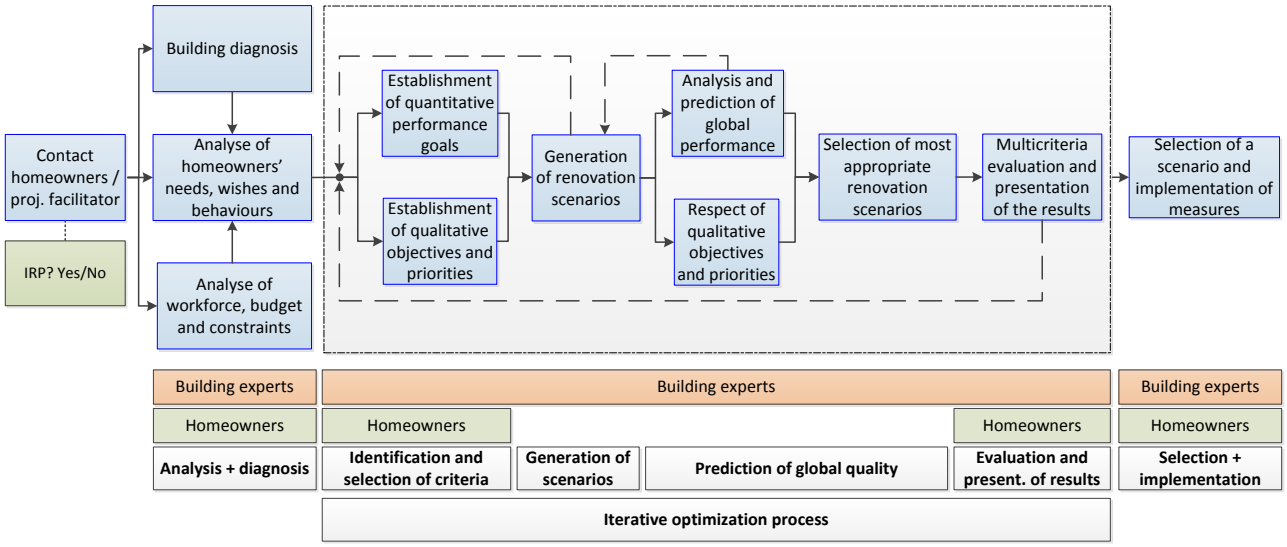


Figure 1: The IRP

2.2. Analysis of the profile of the homeowners

The analysis of the homeowners' profile is close interaction between the homeowners and the building expert. The analysis consists of a questionnaire in two parts answered by the homeowners followed by a discussion.

The first part of the questionnaire consisted of a first set of multiple-choice questions dealing with indoor environment, immaterial values (architectural, emotional/psychological and socio-cultural) and economics (see Appendix 5.1. for the full version of the questionnaire). Answers to those questions allowed finding out the levels of sensitivity for the homeowners / building occupants to specific matters are and for each matter, the corresponding level of discomfort or disturbance. There were 3 or 5 possible answers for each question such as.

If the question was of semi-polar type, there were 3 possible answers: yes, many times; yes, a few times or no, never (see example in Figure 2).

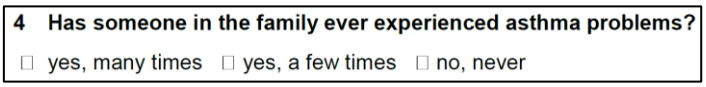


Figure 2: Example of semi-polar question

If the question was of non-polar type, there were 5 possible answers i.e. many times; often; sometimes; infrequently; never. For some questions, the homeowners had the possibility to give more details aside their answer (see example in Figure 3).

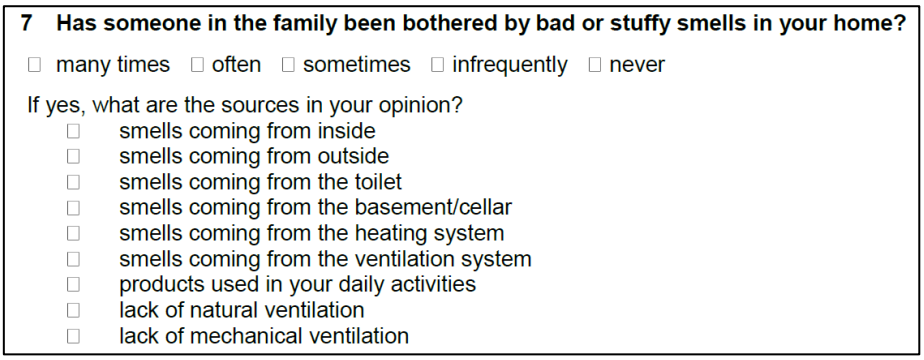
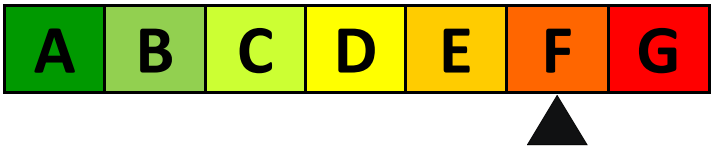


Figure 3: Example of non-polar question

The second part of the questionnaire was directly supported by visuals such as pictures, drawings, plans, etc. (see Appendixes 0 and 5.3 for more details). Visuals were selected to match as close as possible the type, age and style of the studied houses. For that part of the questionnaire, the homeowners were therefore familiarized early on with the unique evaluation scale they had to deal with all through the process. The scale had 7 items including a neutral mid position: very satisfied; quite satisfied; almost satisfied; neutral (neither satisfied nor dissatisfied); neither neutral nor dissatisfied; dissatisfied; very dissatisfied. Every item of the scale was associated to a letter from A to G and to a colour from dark green to dark red via yellow (see Figure 4).

OCCUPANTS



Favourable	**A**	Very satisfied
	B	Quite satisfied
Neutral	**C**	Satisfied if minor changes
	D	Neutral
	E	Minor issues (not neutral but not dissatisfied)
Unfavourable	**F**	Quite dissatisfied
	G	Very dissatisfied

Figure 4: Satisfaction 7 item scale

The second part of the questionnaire was directly combined with a discussion during which knowledge related to the selected criteria and sub-criteria was transferred to the homeowners and awareness was raised.

Immaterial values – aesthetics – roof – please focus now on the following type of roof.
How pleased or satisfied do you feel with the roof global aesthetics (use corresponding evaluation scale)?
Why? (discussion)

Photographer: Mathias Sønderskov Nielsen

Furthermore, themes which need a close interaction with the homeowners were treated for the first time during the discussion. In that way, homeowners were integrated in the process and became active actors in the process rather than just interviewees.

2.3. Identification and selection of the quality and performance criteria

The main purpose of the IRP is to motivate homeowners / decision makers to select a home renovation scenario which is sustainably balanced (personal as societal). It means it has to fulfil their personal needs, wishes, values and behaviours but also some societal needs, which are already incorporated into regulations or standards, or not. A balanced sustainability is therefore defined here as a fair equilibrium between the three pillars of sustainability which are the social, the environmental and the economic pillars.

Deciding on the most favourable renovation scenario with all these stakes in play is not an easy task. Both homeowners and building experts need support. This support can be found through the application of a multiple criteria decision making method and use of corresponding tools. The IRP is based on the qualitative constructivist multiple criteria decision making method called Hermione (reference). The method works on the basis of rules and structures as well as aggregates stakeholders' evaluations into a synthesis which is used to present the final results. To do so, the home renovation stakes are structured into main topics that we call macro-criteria. The various influencing factors stem from the main topics are named criteria. Those factors can regroup even more detailed influencing factors that we call sub-criteria (see Figure 5).

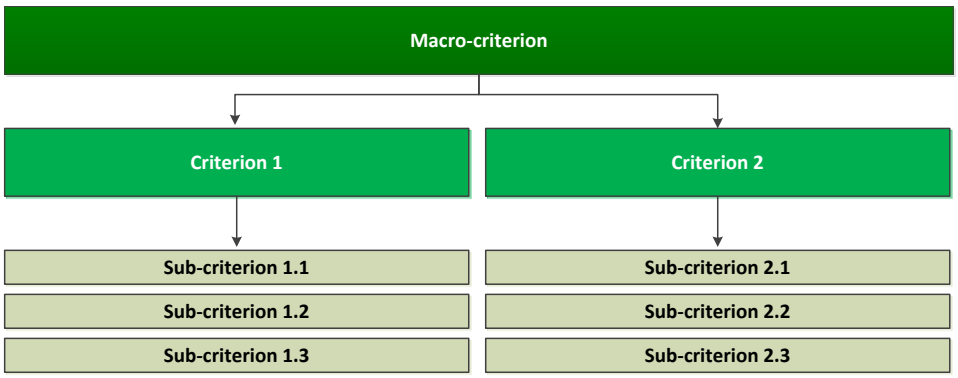


Figure 5: Three-level criteria hierarchy tree

In the context of the application of the IRP on single-family houses (IRP4homes), a new structure of criteria was built on the basis of reaching the most favourable sustainable renovation. The structure complies with the following requirements:

- Exhaustivity: all stakes are represented.
- Non-redundancy: no aspect is taken into account twice.
- Importance equilibrium: all macro-criteria, criteria and sub-criteria have the same importance within their respective hierarchy levels. All criteria are sufficiently important and no criterion is overly important.

The 4 main topics or macro criteria of the criteria structure were the technical aspects of the renovation, the economic situation of the homeowners, the indoor environment quality of the house (comfort and health) and some immaterial values.

<u>Technical aspects</u>

The topic or macro-criteria technical aspects included the degradation state of the building, the energy performance of the building and the technical obsolescence of the building components. The degradation state of the building characterises how worn-out, aged or damaged some of the components constituting the building are. In the macro-criteria "technical aspects", the energy performance of the building represents how close to regulation the building performs in terms of

primary energy consumption of specific utilities (heating, domestic hot water, ventilation and pumps). This is also an approximate way of characterizing the environmental performance of the building and therefore the impact on the environment. The technical obsolescence characterises how outdated some of the building components are. A detailed definition of building obsolescence can be found in the literature. The building obsolescence is characterized and distinguished between physical and behavioural factors and between endogenous and exogenous factors (see Figure 6). In our approach, technical obsolescence does not include wear-out, weathering, fatigue, behavioural use, location of the building, and energy performance of the building. Indeed, a building component not complying with an energy performance regulation is not considered in our approach as obsolete but is treated apart in the sub-criteria "energy performance of the building". In that way, the same issues are not treated twice. The same is seen for the wear-out, weathering and fatigue treated in the criteria "degradation state of the building" and for behavioural use and location of the building which are treated in the criteria "Functionality".

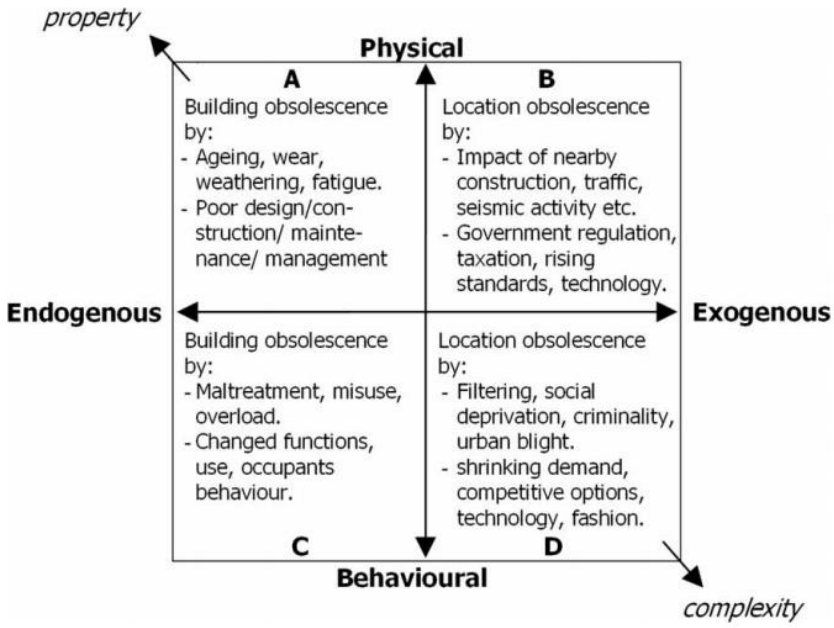


Figure 6: Building obsolescence according to A. Thomsen & Van der Flier (Thomsen & van der Flier, 2011)

Economic situation of the homeowners

In these studies, the economy main performance criterion depends directly on the situation of the homeowners. The macro-criterion was therefore called "Economic situation of the homeowners". This topic includes a rigidly set criteria which is the renovation investment cost (for the coming renovation step and steps possibly implemented in the future but still planned in the meanwhile than the coming renovation step). The economy macro-criteria also included three possibly selectable criteria: the energy savings related to the upgrade of the house and the plus-value of the house after renovation.

Indoor Environment Quality

The topic or macro-criteria indoor environment quality (IEQ) was divided into the following criteria: thermal comfort, acoustic comfort, visual comfort, indoor air quality, healthy home and control. The criteria contained the following sub-criteria:

- User control
  - Control of the temperature
  - Control of the renewal of the air
  - Control of the light
- Thermal comfort
  - Draught, cold from surfaces
  - Temperature in the house
  - Cold/warm surfaces
- Acoustic comfort
  - Sounds coming from the inside
  - Sounds coming from the outside
- Visual comfort
  - Daylight
  - Glare
  - View to the outside
  - Artificial lighting
- Indoor air quality
  - Air pollution
  - Relative humidity
- Healthy home
  - Physical health
  - Well-being

Immaterial values

The possible immaterial value quality criteria to be selected were the functionality, accessibility and spatial organization in the home, the feeling of safety of the homeowners, social-cultural values, emotional or psychological values, aesthetic and artistic values, preservation values, modernization values, and possible other personal values.

All these macro-criteria are closely related to the pillars of sustainability. Indeed, the technical aspects of the renovation represent mainly the environmental pillar even it has also an impact on the 2 other pillars of sustainability. The economic outcome represents the economic pillar. Finally the indoor environment quality of the house and the immaterial values represent the social pillar. Even 2 macro-criteria out of 4 have a character mainly social, we found the representation of a sustainable renovation quite fair for home renovation.

While the macro-criteria level of the hierarchal tree is rigidly set (see dark green cells in Figure 7), the stemming criteria level is more flexible. Indeed, while all building profile based criteria are mandatory in the hierarchal tree (see light green cells in Figure 7), the selection of the homeowners' profile based criteria depends on the homeowners' sensitivities and personal values (see grey cells in Figure 7).

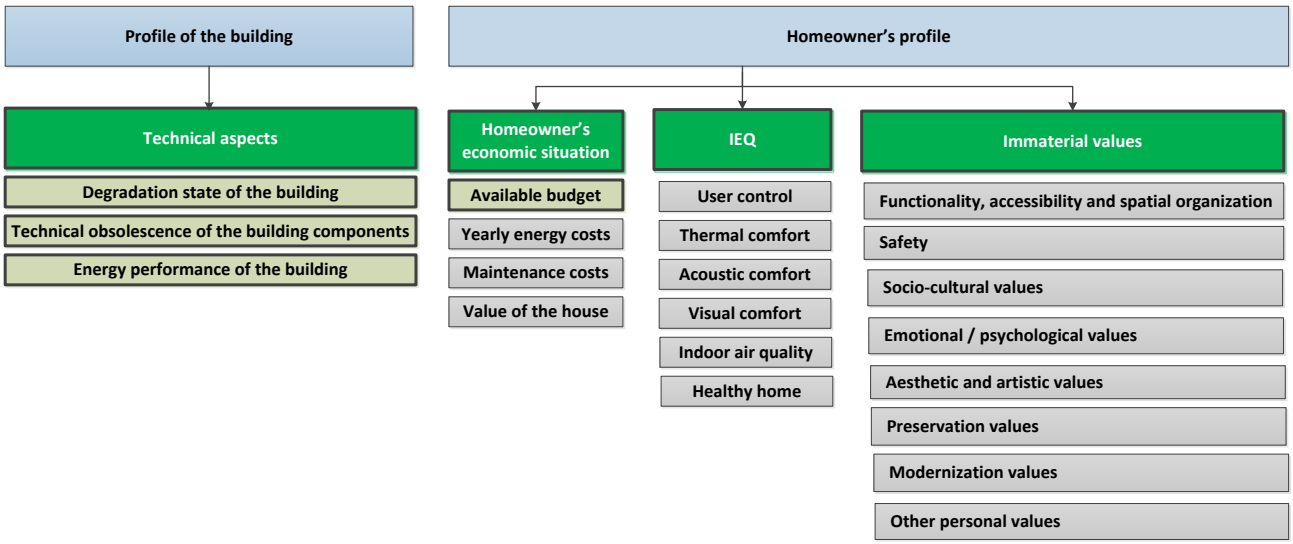


Figure 7: Criteria tree – step 1

Indeed, there is no point of selecting criteria which would have no importance in the eyes of the decision makers. After the questionnaire was answered by the homeowners, the answers were analysed and some criteria were therefore added and some removed and then used as main input for the discussion (see new light green and red cells in Figure 8).

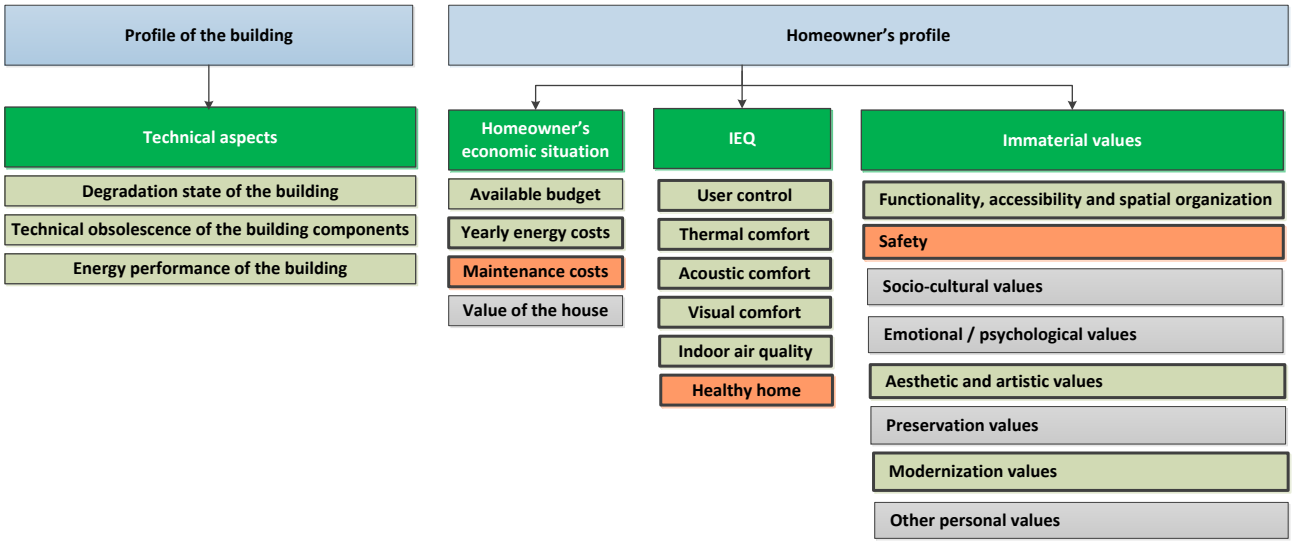


Figure 8: Criteria tree – step 2

Then during the discussion and evaluations with use of visual supports, some criteria were then confirmed, added or removed (see Figure 9).

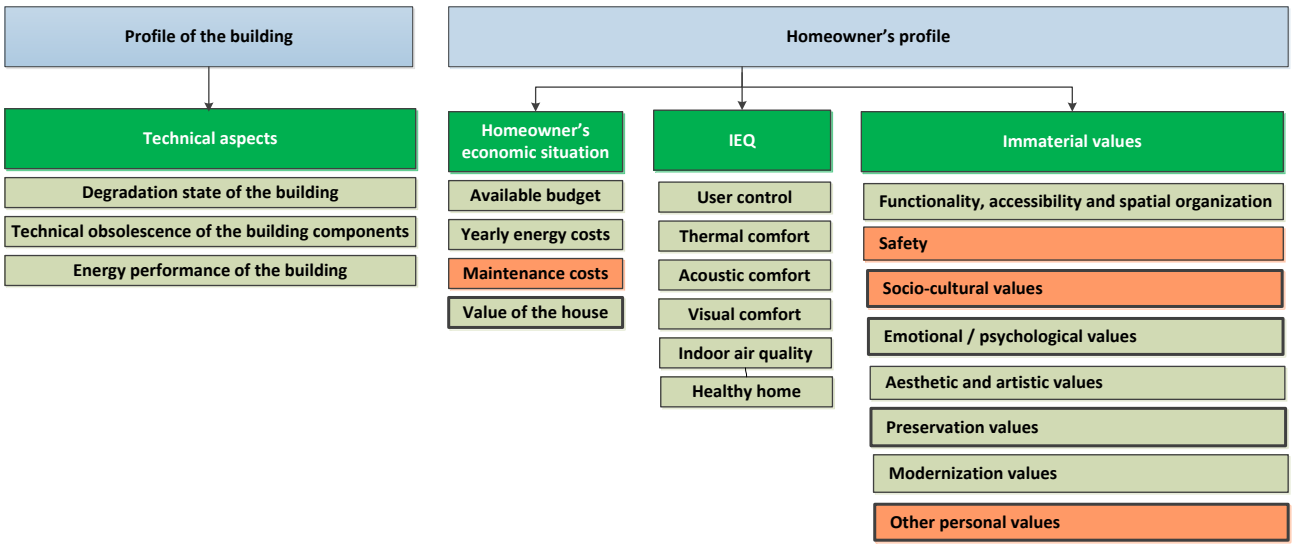


Figure 9: Criteria tree – step 3

Here below is therefore the criteria hierarchal tree for case study No. 1 (see Figure 10). It shows all criteria finally taken into account for the decision making process undertaken with the homeowners.

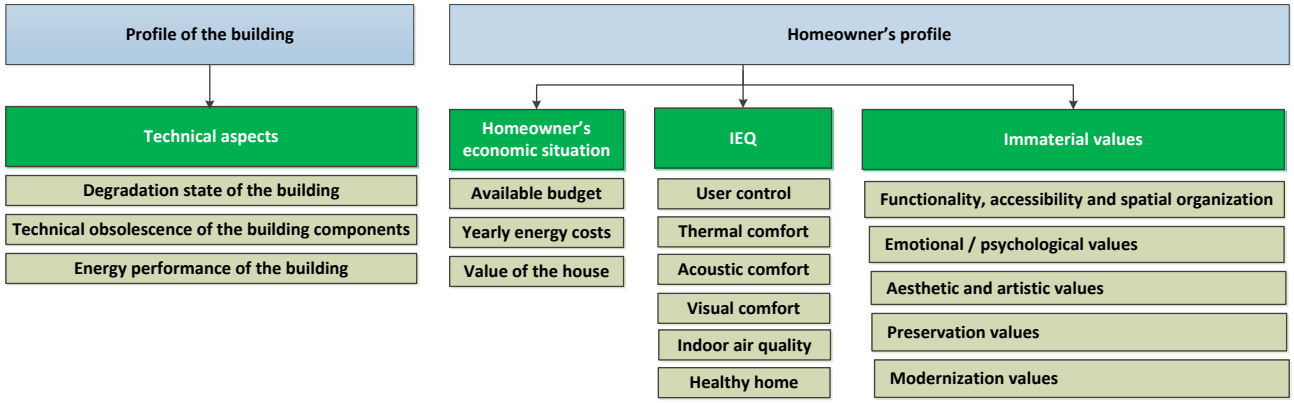


Figure 10: Criteria tree – step 4

2.4. Evaluations for the building in the existing conditions (before renovation)

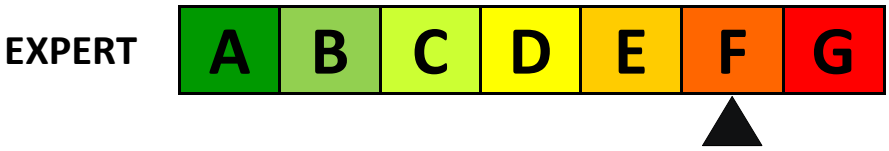
2.4.1. Build-up of the evaluation scale

The evaluation scale has been built up based on a modification of Hermione method evaluation scale (Flourentzou, Greuter, & Roulet, 2003). In Hermione method, the scale includes three levels of favourableness (favourable, neutral and unfavourable) divided in 7 items. The seven items are described as Green (G): favourable, Green minus (G-): favourable with some reserves, Yellow plus (Y+): neutral with positive elements, Yellow (Y): neutral, Yellow minus (Y-): neutral with negative elements, Red plus (R+): unfavourable with some positive elements and Red ®: unfavourable. In order to make the homeowners understand easier the scale, more colours as well as letters from A to G have replaced the three colours with differentiations of Hermione. Besides being more visual for the homeowners, the scale also reminds a scale that homeowners already know from the energy labelling for household appliances (washing machines, etc.) or for the energy performance of buildings.

2.4.2. Diagnosis of the building and evaluation of the technical aspects

Technical aspects

All technical aspects were all uniquely treated by the building expert. Thanks to a building inspection, the degradation state and the technical obsolescence of the building components were qualitatively evaluated. The inspection was visual with the use of a few basic measuring instruments plus a thermal infrared camera. The 7 item evaluation scale used was similar to the scale used by the homeowners but with different attributes: excellent, good, good if minor changes, neutral, minor issues (not neutral but not poor), poor, critical (see Figure 11). The building expert was therefore familiarized with the evaluation scale at the inspection itself and the learning process went quick and easy.



Favourable	**A**	Excellent
	B	Good
Neutral	**C**	Better than neutral but not good
	D	Neutral
	E	Worse than neutral but not poor
Unfavourable	**F**	Poor
	G	Very poor

Figure 11: Expert qualitative evaluation 7 item scale

The inspection was targeting all building components divided into the following categories: external face of the roof; internal face of the roof; exterior walls, windows, doors; ceilings above heated areas; ceiling above cold areas; interior ceilings; interior walls; balconies, loggias, terraces; plumbing and electrical installations; heating system and hot water generation. For both the degradation state and the technical obsolescence, the building expert was free to evaluate building components individually or evaluating regrouped categories as a whole (see example in Figure 12). The entire building diagnosis sheet is available in the appendixes of this document (see Appendix 0).

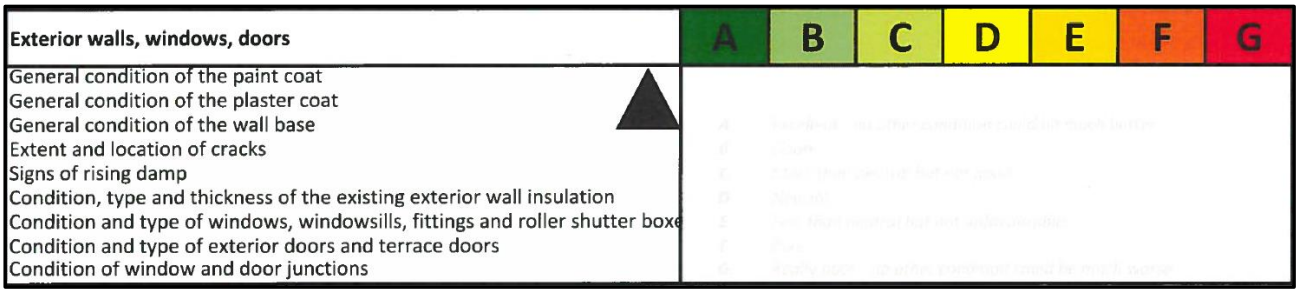
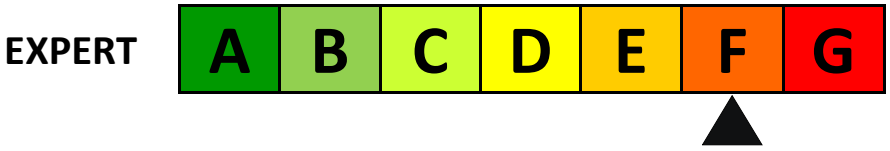


Figure 12: Example of a detailed evaluation of degradation state and technical obsolescence

After inspecting the building envelope via the use of thermal infrared imaging (qualitative evaluation), the energy performance of the building was quantitatively evaluated via building energy calculations and simulations. The programs used were Be10 (Statens Byggeforskningsinstitut (SBi), 2012) and BEopt (National Renewable Energy Laboratory, 2014). Models were built from measurements on-site or from drawings data and energy label report when available. For the

evaluation of the energy performance of the building (see Figure 13), the evaluation was aligned to the BR10 Danish energy label scale. This means that the building expert agreed that reaching an energy label B after renovation was good, while reaching an energy label A was excellent (in other words selecting a renovation scenario which would bring the building to an energy label A or B was a favourable situation). In order to make a distinction in the presentation of the results between the very energy performing scenarios, the attribute A was divided into sub-attributes A10, A15, A20 and A0. A10 is the minimum energy frame requirement for residential buildings from 2010 in Denmark, A15 from 2015, A20 from 2020 and A0, a net zero energy building according to the ZEB centre definition (Strategic Research Centre for Zero Energy Buildings, Aalborg University, 2014).



Favourable	**A**	A10: < 52,5+(1650/S)
	B	B: < 70+(2200/S)
Neutral	**C**	C: < 110+(3200/S)
	D	D: < 150+(4200/S)
	E	E: < 190+(5200/S)
Unfavourable	**F**	F: < 240+(6500/S)
	G	G: > 240+(6500/S)

Units are in [KWh/m^2.y]; S is the heated gross floor area [m^2]

Figure 13: Expert quantitative evaluation 7 item scale for the energy performance of the building

2.4.2.1. Degradation state and technical obsolescence

The inspection of each house took about half a day for each. After evaluating all the diverse building components thanks to the scale, the building expert aggregated the results in his mind to give a global state of degradation and of technical obsolescence for the house as a whole. Even if some building components were for some in good condition, for others in critically poor condition, the building expert concluded that the case study No. 1 house was globally in a very poor condition for both the global degradation state of the house and the technical obsolescence of the building components, The case study No. 2 house was globally in poor condition for both the global degradation state of the house and the technical obsolescence of the building components. The results are given for both houses in the existing conditions (before renovation) in the following figures (see Figure 14 and Figure 15).

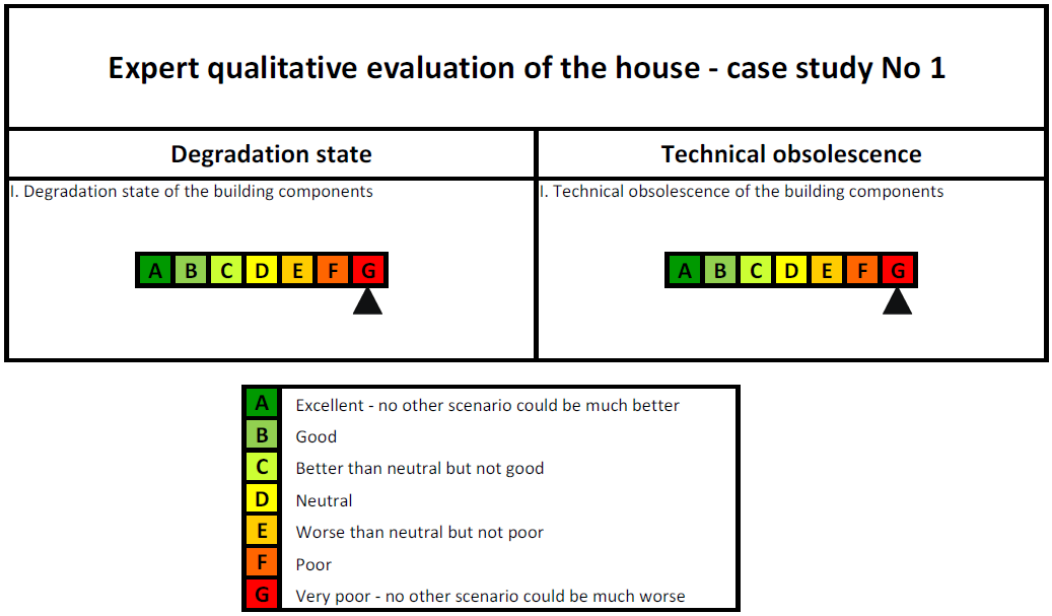


Figure 14: Expert qualitative evaluation of the house – case** study **No. 1

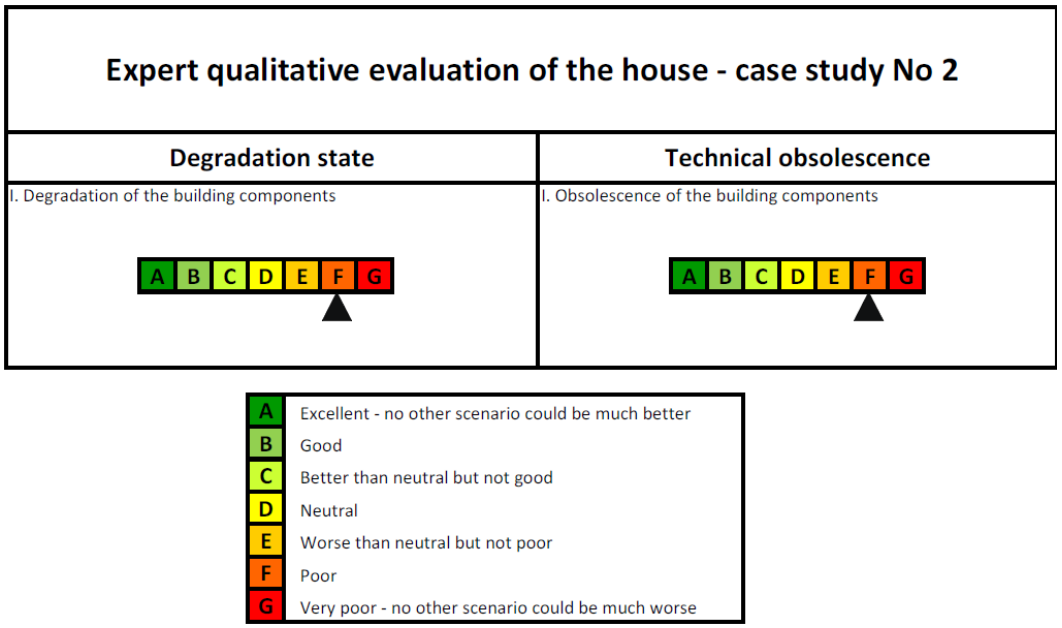


Figure 15: Expert qualitative evaluation of the house – case study No. 2

2.4.2.2. Energy performance of the building

The energy performance of the building was quantitatively evaluated thanks to the program Be10 (Statens Byggeforskningsinstitut (SBi), 2012) and then confirmed via building simulations in BEopt (National Renewable Energy Laboratory, 2014). The results are given for both houses in the existing conditions (before renovation) in the following figures (see Figure 16 and Figure 17).

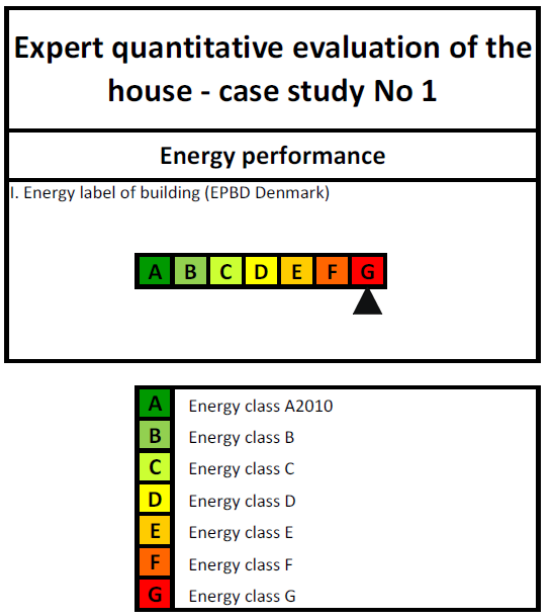


Figure 16: Expert quantitative evaluation of the house – case study No. 1

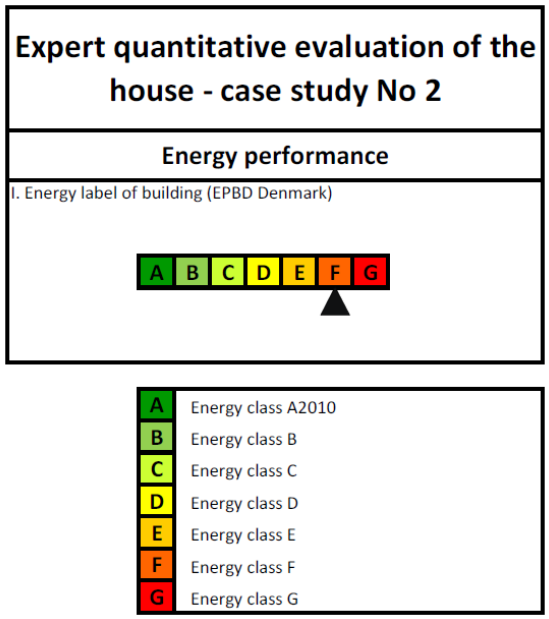


Figure 17: Expert qualitative evaluation of the house – case study No. 2

2.4.3. Evaluation of the indoor environment quality

In order to improve the transfer of knowledge between the building expert and the homeowners (who are building non-expert decision-makers), guiding sheets were used as supports for every evaluation. For every criterion, they included the diverse themes to present with notions to explain. After a first introduction of the different themes, the building expert had to relate these notions with the house in the existing conditions. After exchange of knowledge and raise of awareness, both the homeowners and the building expert interactively evaluated qualitatively the diverse indoor environment quality criteria. They finally agreed on the results.

2.4.3.1. Evaluation of the thermal comfort

The guiding sheet used by the building expert and the homeowners for the evaluation of the thermal comfort included the following themes: draught and cold coming from surfaces, the temperature in the house and cold or warm surfaces (see Figure 18).

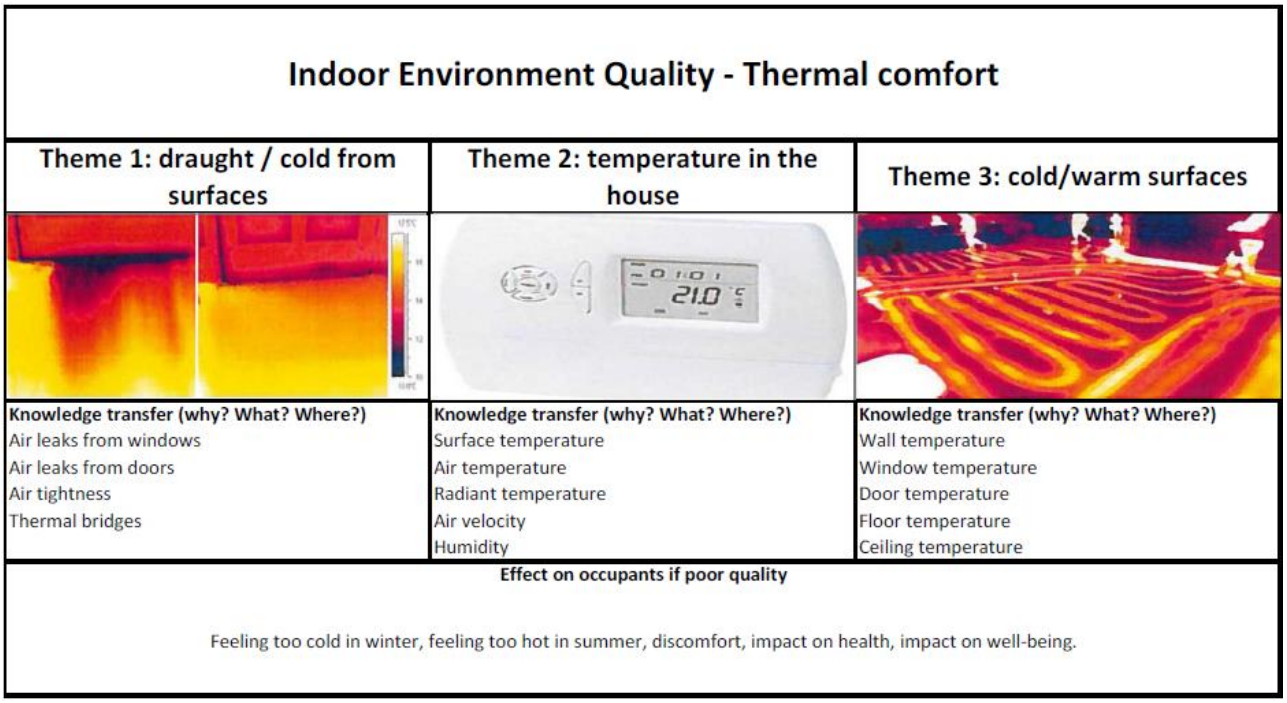


Figure 18: Guiding sheet for the evaluation of the thermal comfort

Concepts such as air leaks, airtightness and thermal bridges were explained and illustrated thanks to the support of thermal infrared images (see Figure 19).

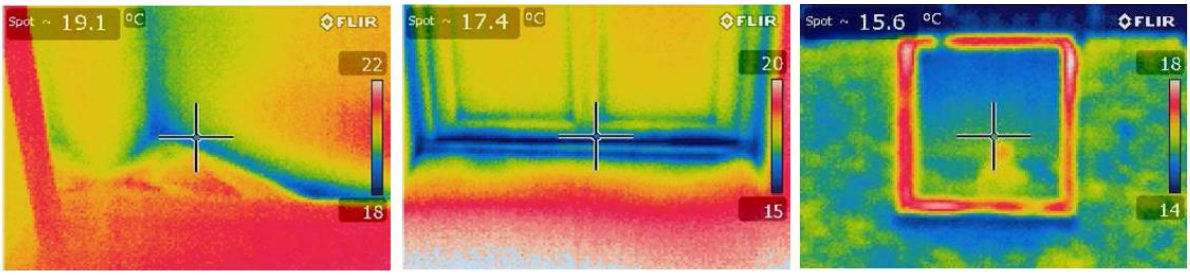


Figure 19: Thermal infrared images of the studied house (illustration of lack of airtightness, air leaks and thermal bridges)

The effects or impacts on the occupants in case of poor quality of the thermal comfort were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the thermal comfort done by the building expert was presented to the homeowners and justified (see Figure 20 for case study No. 1 and Figure 21 for case study No. 2).

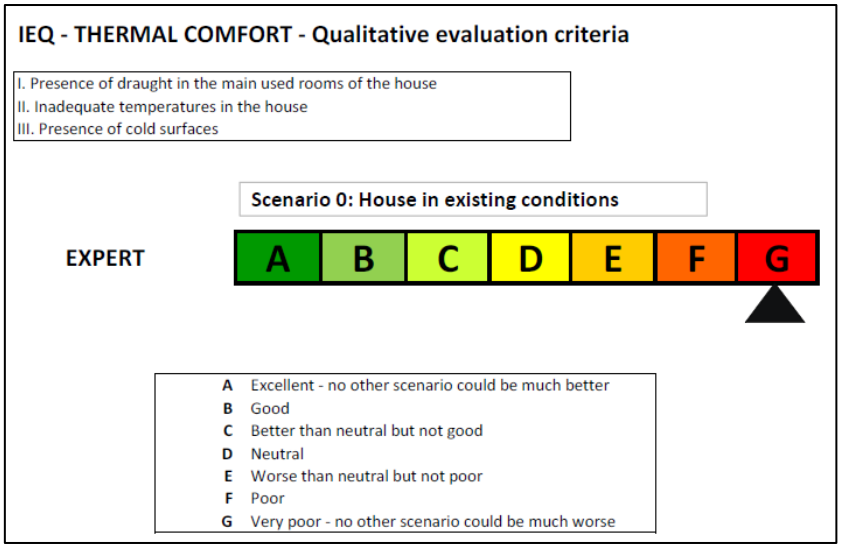


Figure 20: Building expert evaluation of the thermal comfort in the case study No. 1 house in the existing conditions

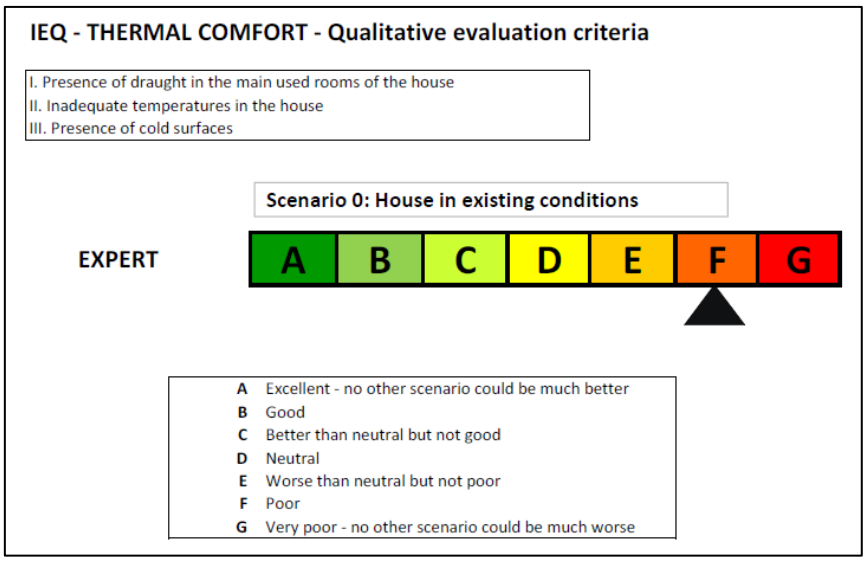


Figure 21: Building expert evaluation of the thermal comfort in the case study No. 2 house in the existing conditions

Then, the homeowners were asked to evaluate themselves the thermal comfort of their house in the existing conditions using the satisfaction scales (see Figure 22 - case study No. 1 on the left and case study No. 2 on the right). In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of thermal comfort.

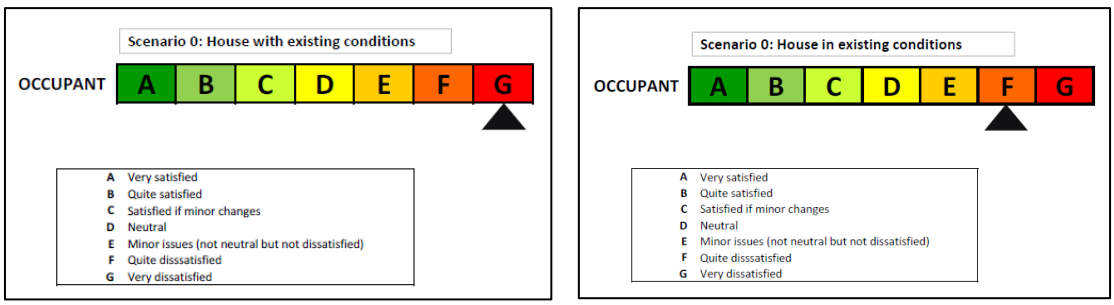


Figure 22: Evaluation of the thermal comfort by the homeowners for both case studies in the existing conditions of the house

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the thermal comfort (see Figure 23 and

Figure 24). In case of disagreement, more weight was given to the homeowners' evaluation (e.g. expert evaluated a neutral state "D" whereas the homeowners evaluated a level of satisfaction "G", the global evaluation ended on an "F" poor / quite dissatisfied. It is to be noticed that very few situations of disagreement were met during both case studies; most global evaluation results between the building expert and the homeowners came natural.

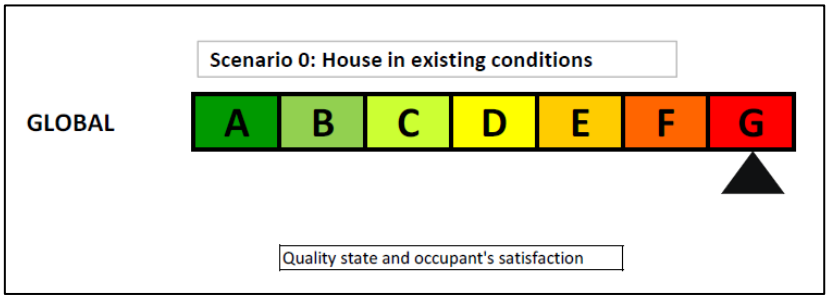


Figure 23: Global evaluation of the thermal comfort quality of case study No. 1

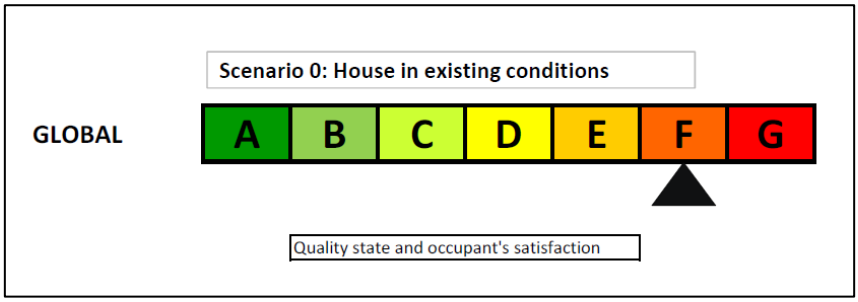


Figure 24: Global evaluation of the thermal comfort quality of case study No. 2

2.4.3.2. Evaluation of the indoor air quality

The guiding sheet used by the building expert and the homeowners for the evaluation of the thermal comfort included the following themes: air pollution and relative humidity (see Figure 25).

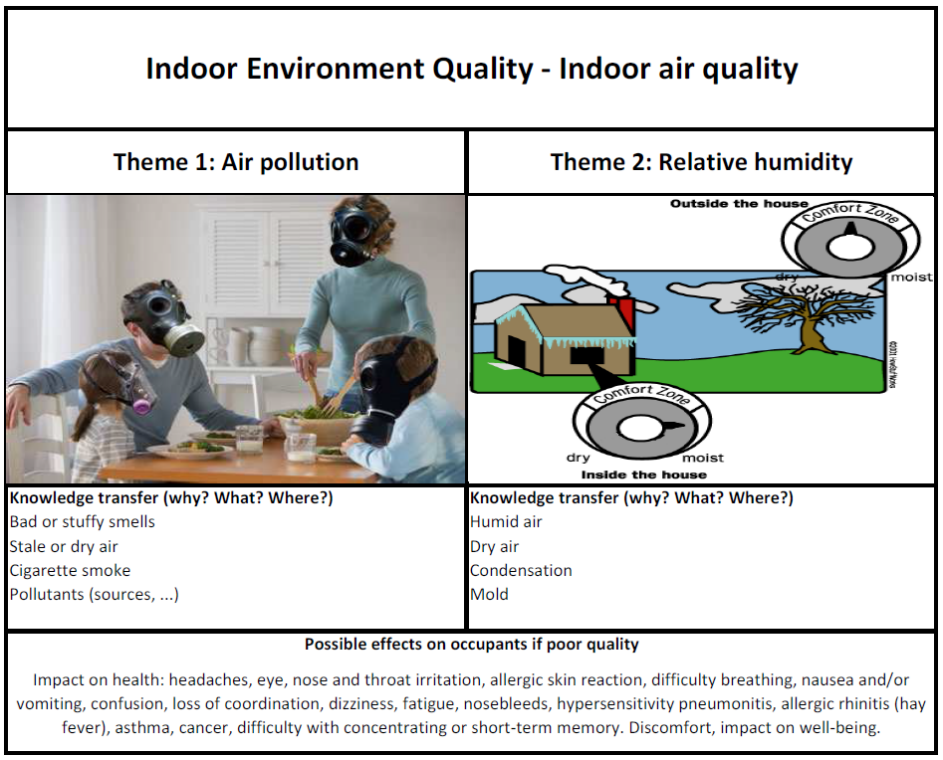


Figure 25: Guiding sheet for the evaluation of the indoor air quality. Sources of photographs: http://www.biomaxenvironmental.com/wp-content/uploads/2012/08/indoor-air-pollution-11.jpg and http://home.howstuffworks.com/humidifier2.htm, May 2013

The effects or impacts on the occupants in case of poor quality of indoor air quality were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the indoor air quality done by the building expert was presented to the homeowners and justified (see Figure 26 for case study No. 1 and Figure 27 for case study No. 2).

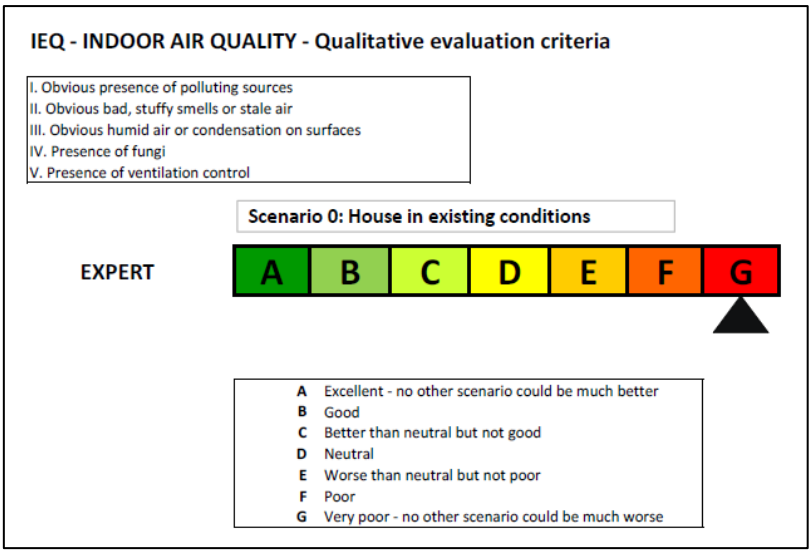


Figure 26: Building expert evaluation of the indoor air quality for case study No. 1 in the existing conditions of the house

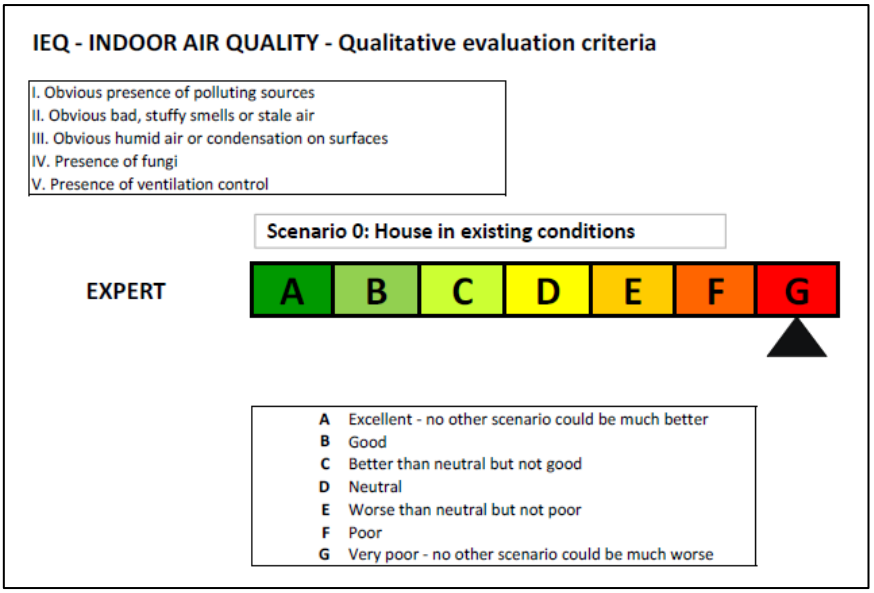


Figure 27: Building expert evaluation of the indoor air quality for case study No. 2 in the existing conditions of the house

In the same approach that for the thermal comfort, the homeowners were asked to evaluate themselves the indoor air quality in the existing conditions using the satisfaction scales (see Figure 28: for case study No. 1 on the left and for case study No. 2 on the right).

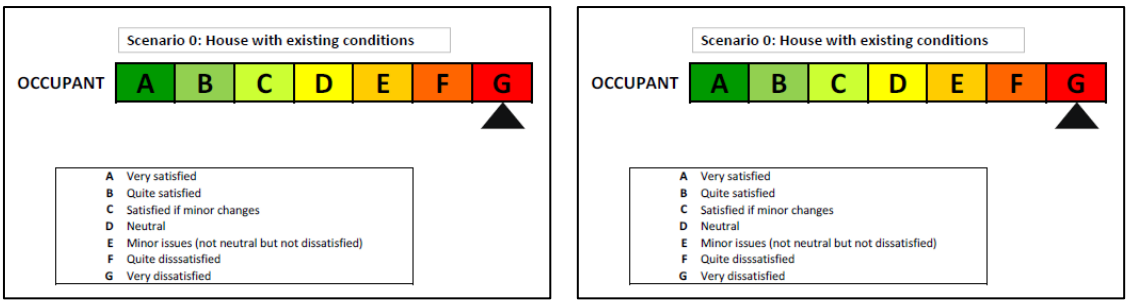


Figure 28: Evaluation of the indoor air quality by the homeowners for both case studies in the existing conditions of the house

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the indoor air quality (see Figure 29 and Figure 30). For both case studies, an agreement between the parties naturally came to a G evaluation Very poor / very dissatisfied.

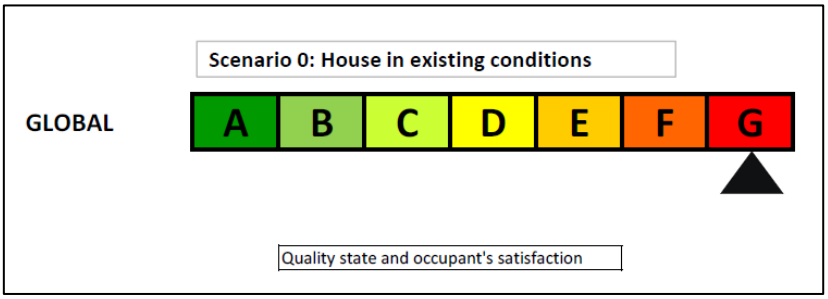


Figure 29: Global evaluation of the indoor air quality of case study No. 1

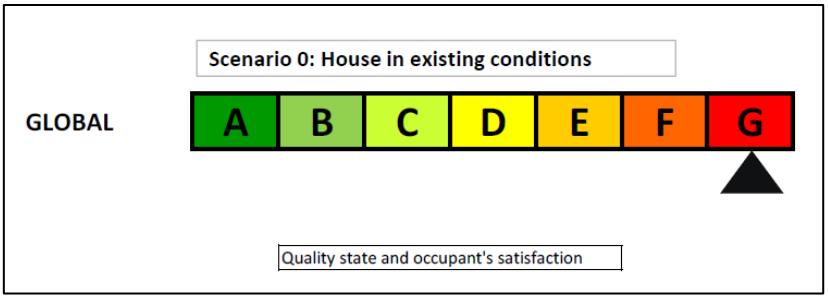


Figure 30: Global evaluation of the indoor air quality of case study No. 2

2.4.3.3. Evaluation of the visual comfort

The guiding sheet used by the building expert and the homeowners for the evaluation of the visual comfort included the following themes: daylight, glare, view to the outside and artificial lighting (see Figure 31).

Indoor Environment Quality - Visual comfort

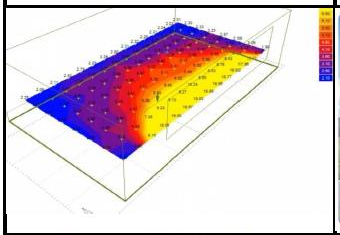
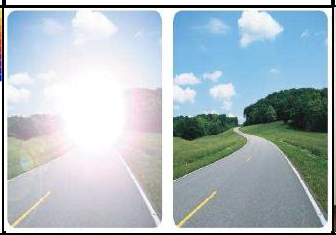
Theme 1: Daylight	Theme 2: Glare	Theme 3: View to the outside	Theme 4: Artificial lighting
			
Knowledge transfer (why? What? Where?) Autonomy and penetration of light Types of daylight (lateral, zenital, tubes) Colors of surfaces (reflection, diffusion)	**Knowledge transfer (why? What? Where?)** Solar protections (vegetal, fix, mobile)	**Knowledge transfer (why? What? Where?)** View from most used locations Angle of view (width of windows) View accross rooms	**Knowledge transfer (why? What? Where?)** Link daylight vs. artificial lighting Illumination (lux) Spectrum of light (redish from 2-3000K and bluish from 3000K and beyond) Color of light and visual fatigue
Effect on occupants if poor quality Visual discomfort, feeling of confinement, feeling of sadness, pain in eyes, disconnection with the outdoor, feeling of locked-in, feeling that rooms are too small, feeling that rooms are not well integrated or connected, difficulty of doing some tasks properly, stress, fatigue.			

Figure 31: Guiding sheet for the evaluation of the visual comfort. Sources of photographs: http://sustainabilityworkshop.autodesk.com/buildings/measuring-light-levels, http://www.selectspecs.com/info/lens-

The effects or impacts on the occupants in case of poor visual comfort were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the visual comfort done by the building expert was presented to the homeowners and justified (see Figure 32 for case study No. 1 and Figure 33 for case study No. 2).

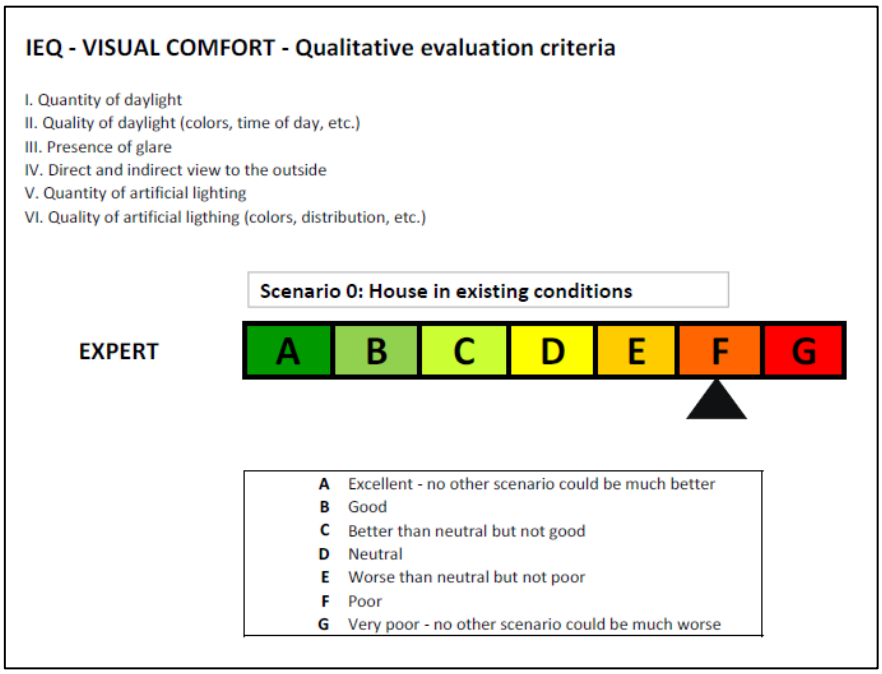


Figure 32: Building expert evaluation of the visual comfort for case study No. 1 in the existing conditions of the house

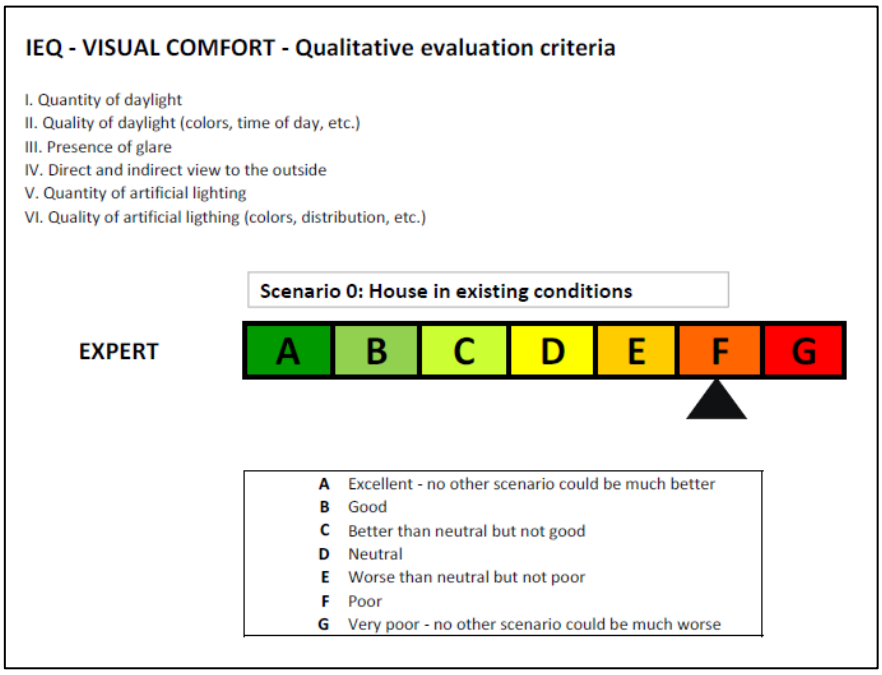


Figure 33: Building expert evaluation of the visual comfort for case study No. 2 in the existing conditions of the house

In the same approach that for the previous criteria, the homeowners were asked to evaluate themselves the visual comfort in the existing conditions using the satisfaction scales (see Figure

34 - case study No. 1 on the left and case study No. 2 on the right). During the evaluation, the homeowners decided to evaluate the sub-criteria first before aggregating the result in their minds to the visual comfort criteria as a whole. This was certainly due to the fact there were more sub-criteria within the visual comfort criteria than for the previous evaluated criteria.

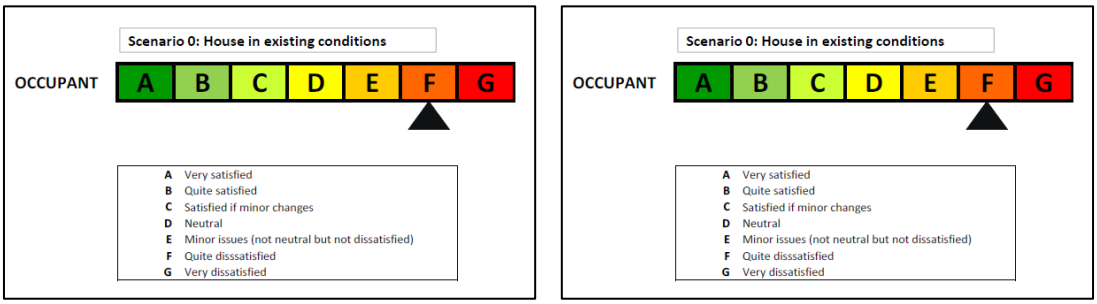


Figure 34: Visual comfort evaluation according the homeowners

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the visual comfort (see Figure 35 and Figure 36). For both case studies, an agreement between the parties naturally came to an F evaluation “very poor / very dissatisfied”.

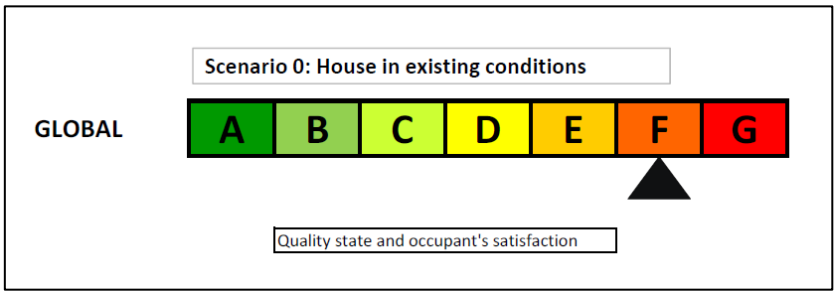


Figure 35: Global evaluation of the visual comfort of case study No. 1

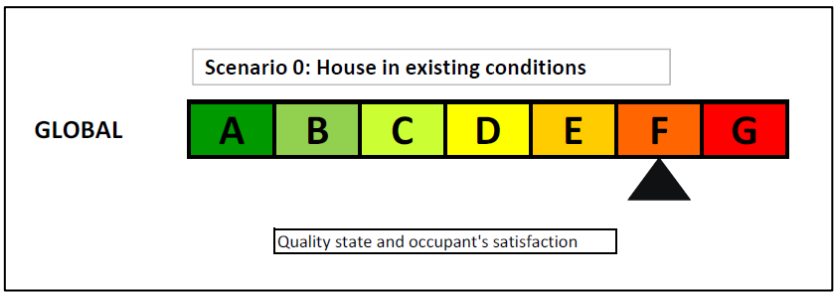


Figure 36: Global evaluation of the visual comfort of case study No. 2

2.4.3.4. Evaluation of the acoustic comfort

The guiding sheet used by the building expert and the homeowners for the evaluation of the acoustic comfort included the following themes: sounds coming from the indoor and sounds coming from the outdoor (see Figure 37).

Figure 37: Guiding sheet for the evaluation of the acoustic comfort. Sources of photographs: http://www.thepollutionfacts.com/2013/02/noise-pollution-facts.html, May 2013

The effects or impacts on the occupants in case of poor acoustic comfort were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the acoustic comfort done by the building expert was presented to the homeowners and justified (see Figure 38 for case study No. 1 and Figure 39 for case study No. 2).

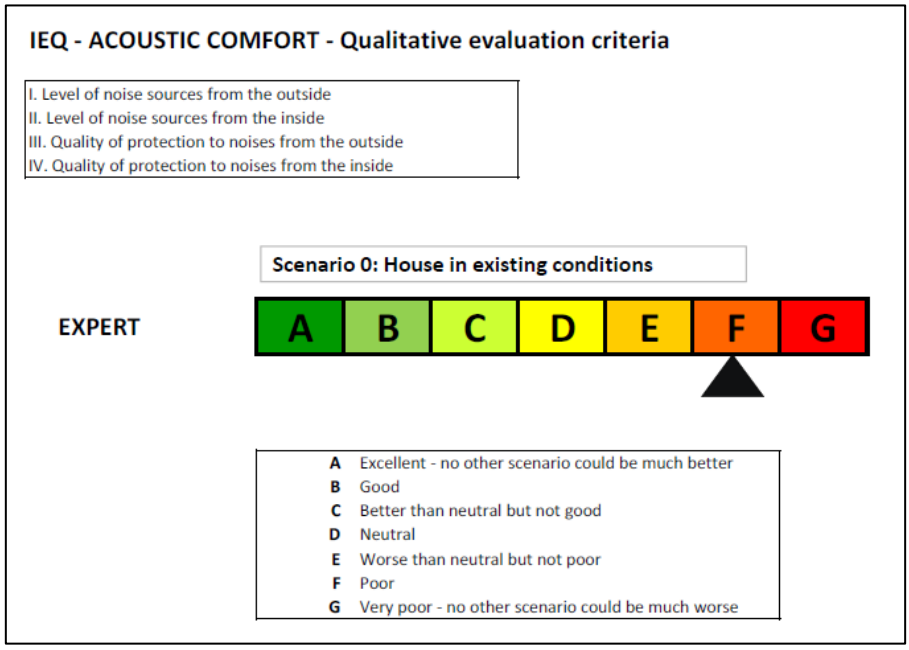


Figure 38: Building expert evaluation of the acoustic comfort in the case study No. 1 in the existing conditions of the house

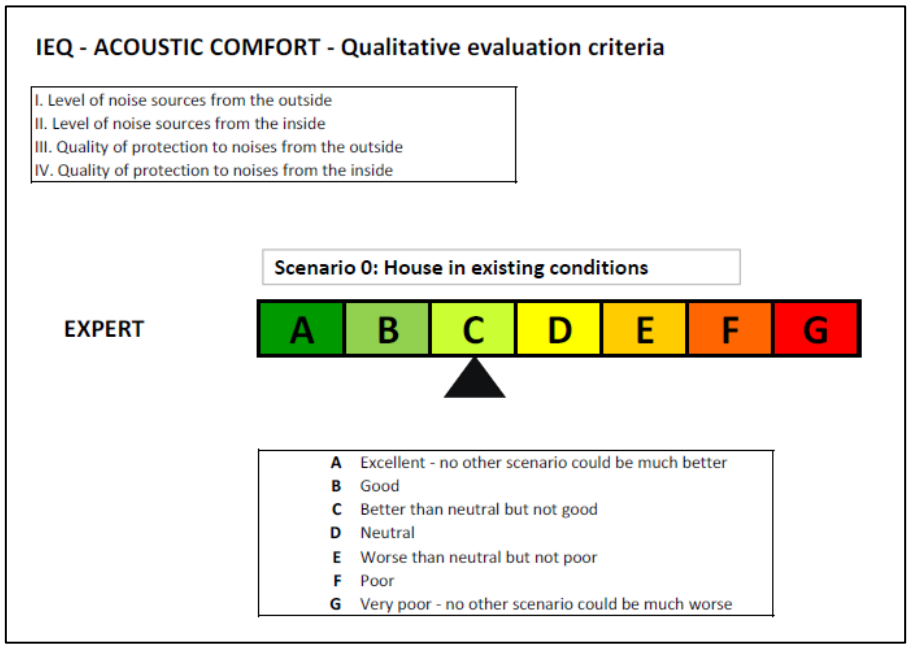


Figure 39: Building expert evaluation of the acoustic comfort in the case study No. 2 in the existing conditions of the house

In the same approach that for the evaluation of the previous criteria, the homeowners were asked to evaluate themselves the acoustic comfort in the existing conditions using the satisfaction scales (see Figure 40 - case study No. 1 on the left and case study No. 2 on the right). All homeowners were pretty confident about how satisfied they were and they all agreed with the building expert evaluation.

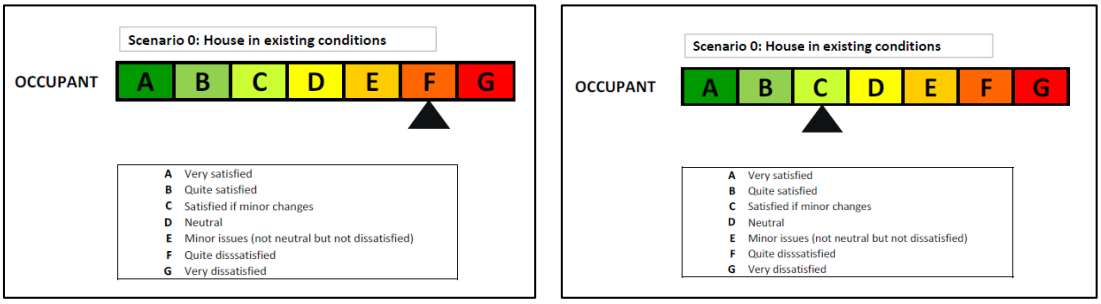


Figure 40: Acoustic comfort evaluation according the homeowners for respectively case study No. 1 and No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the acoustic comfort (see Figure 41 and Figure 42). For both case studies, an agreement between the parties naturally came to an F “Poor / Quite dissatisfied” (case study No. 1) and to a C “Better than neutral but not good / Satisfied if minor changes” (case study No. 2).

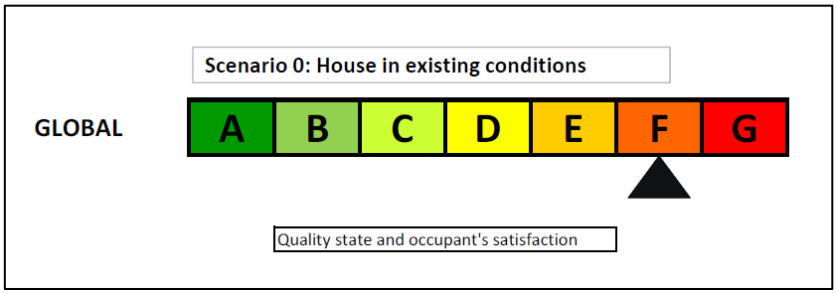


Figure 41: Global evaluation of the acoustic comfort of case study No. 1

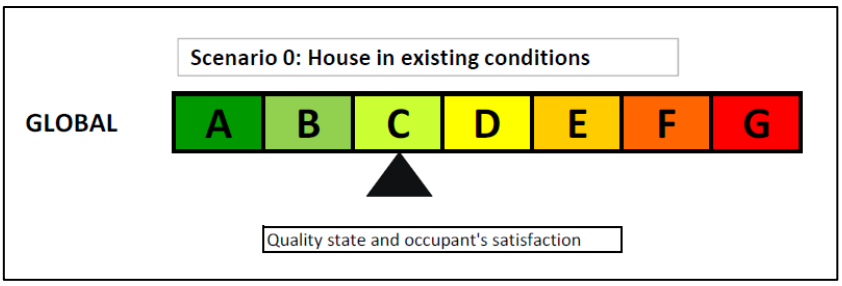


Figure 42: Global evaluation of the acoustic comfort of case study No. 2

2.4.3.5. Evaluation of the user control

The guiding sheet used by the building expert and the homeowners for the evaluation of the user control included the following themes: control of the temperature, control of the renewal of air and control of light (see Figure 43).

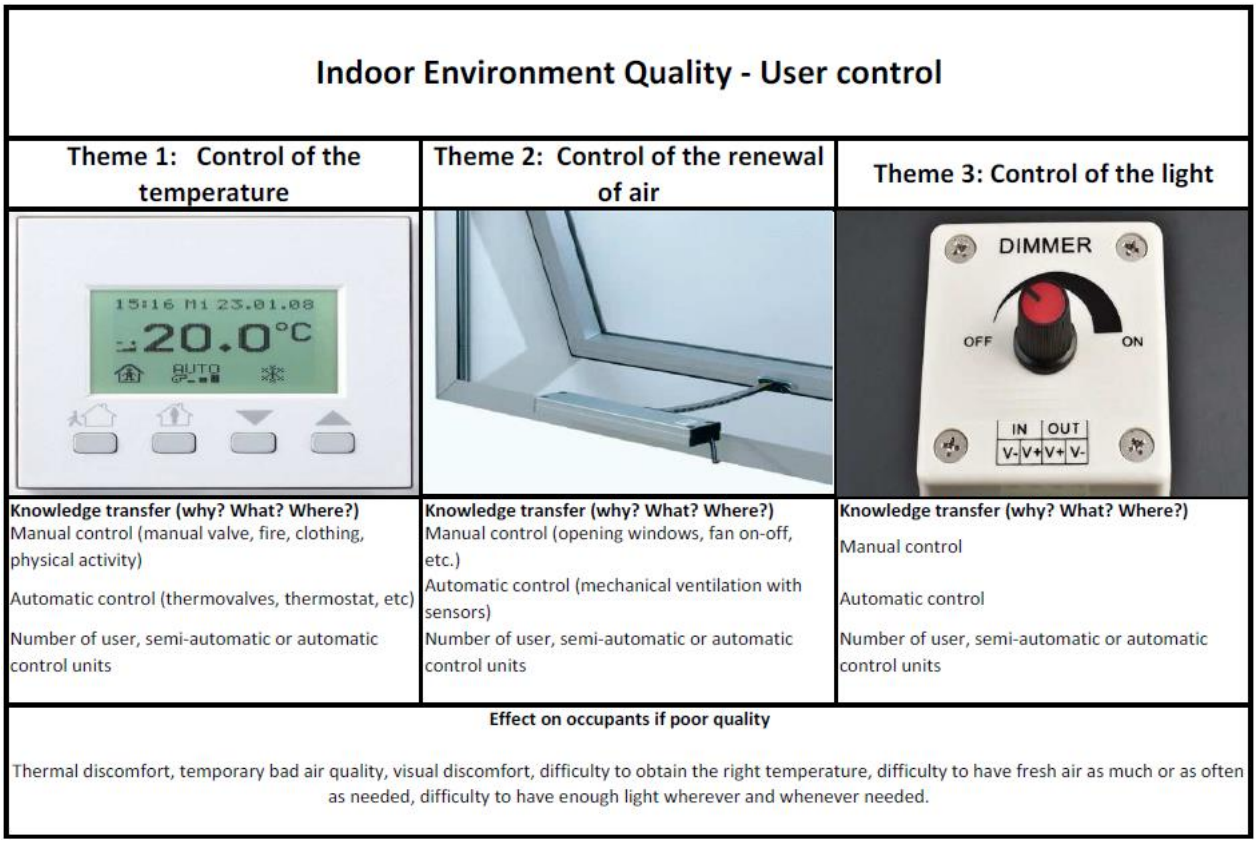


Figure 43: Guiding sheet for the evaluation of the user control. Sources of photographs: http://www.bizrice.com/products/Room-Temperature-Control-System.html, http://www.arcat.com/arcatcos/cos35/arc35600.html and http://www.allansonled.com/en/products/led-dimmer, May 2013

The effects or impacts on the occupants in case of poor user control were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the user control done by the building expert was presented to the homeowners and justified (see Figure 44 for case study No. 1 and Figure 45 for case study No. 2).

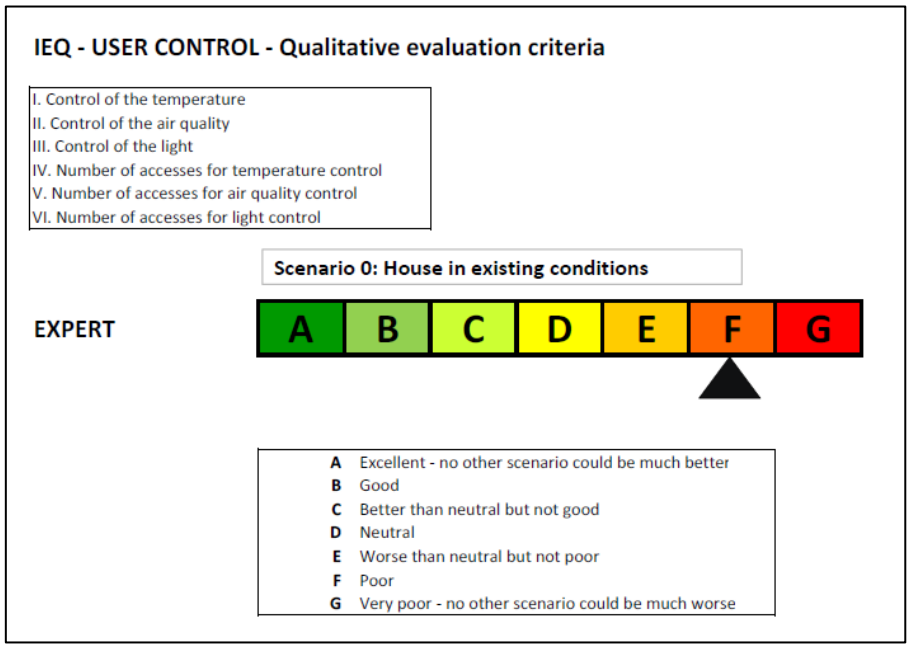


Figure 44: Building expert evaluation of the user control in the case study No. 1 in the existing conditions of the house

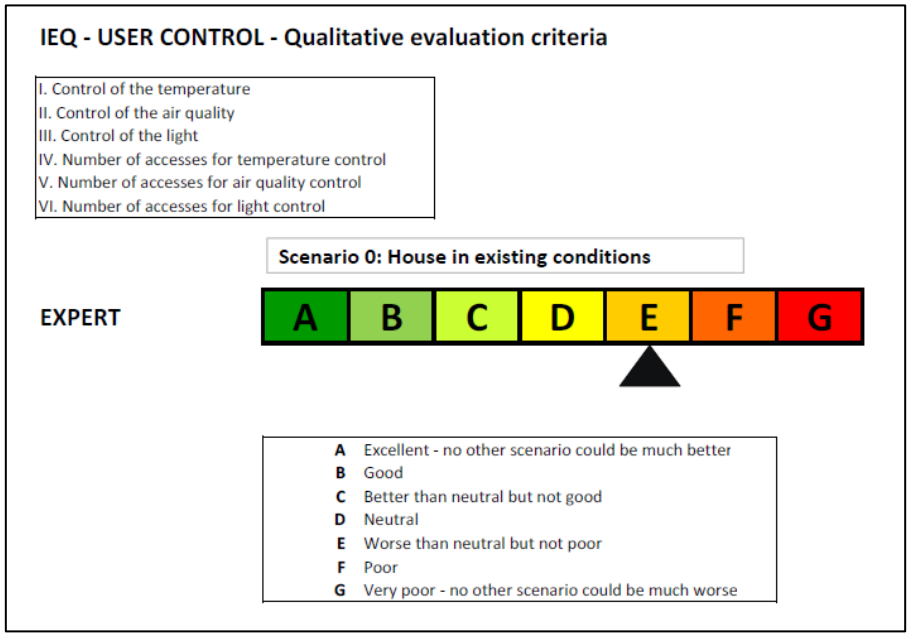


Figure 45: Building expert evaluation of the user control in the case study No. 2 in the existing conditions of the house

In the same approach that for the evaluation of the previous criteria, the homeowners were asked to evaluate themselves the user control in the existing conditions using the satisfaction scales (see Figure 46 - case study No. 1 on the left and case study No. 2 on the right). All homeowners were pretty confident about how satisfied they were and they all agreed with the building expert evaluation.

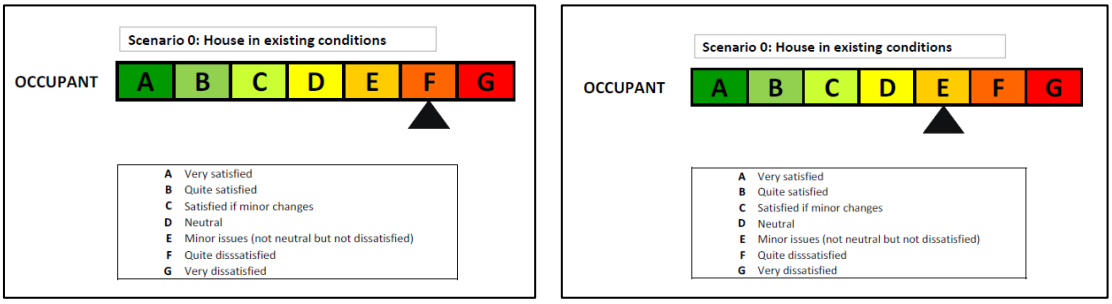


Figure 46: User control evaluation according the homeowners for respectively case study No. 1 and No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the user control (see Figure 47 and Figure 48). For both case studies, an agreement between the parties naturally came to an F "Poor / Quite dissatisfied" (case study No. 1) and to an E "worse than neutral but not poor/not neutral but not dissatisfied" (case study No. 2).

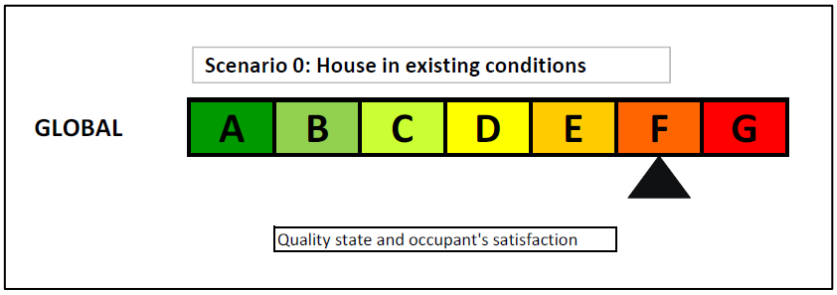


Figure 47: Global evaluation of the user control of case study No. 1

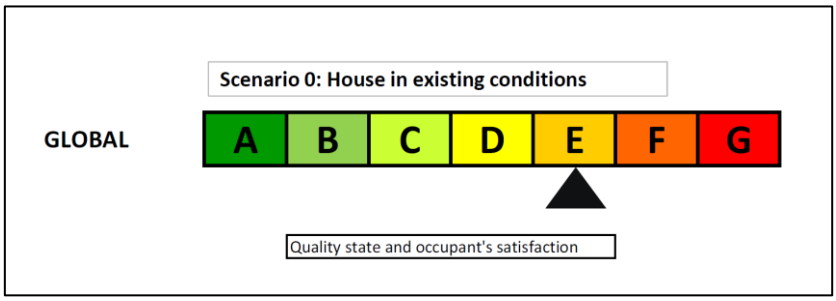


Figure 48: Global evaluation of the user control of case study No. 2

2.4.3.6. Evaluation of the health conditions in the home

The guiding sheet used by the building expert and the homeowners for the evaluation of the health conditions in the home included the following themes: physical health and well-being (see Figure 49).

<table>
<tr><th colspan="2">Health - Healthy home</th></tr>
<tr><th>Theme 1: Physical health</th><th>Theme 2: Well-being</th></tr>
<tr><td>Illustration
  </td><td>Illustration
  </td></tr>
<tr><td>Knowledge transfer (why? What? Where?)
dry or watery eyes, stuffy or runny nose, dry or irritated throat, feeling of being oppressed, dry or irritated skin, headaches, lethargy or fatigue, back or shoulder aches, stress</td><td>Knowledge transfer (why? What? Where?)
What is well-being?</td></tr>
<tr><td>Effect on occupants if poor quality
Physical or/and psychological symptoms</td><td>Effect on occupants if poor quality
Unhappiness
Stress (annoyments)
Sorrow
Fatigue, lethargy</td></tr>
</table>

Figure 49: Guiding sheet for the evaluation of the health conditions in the home. Sources of photographs: http://www.weather.com/health/fitness-exercise/should-i-exercise-2012-06-01 and http://loughboroughsport.com/corporate-well-being, May 2013

The effects or impacts on the occupants in case of poor health conditions in the home were presented to the homeowners and they were directly asked whether they had experienced those effects and if yes, where, when or how. From there, the evaluation of the health conditions in the home done by the building expert was presented to the homeowners and justified (see Figure 50 for case study No. 1 and Figure 51 for case study No. 2).

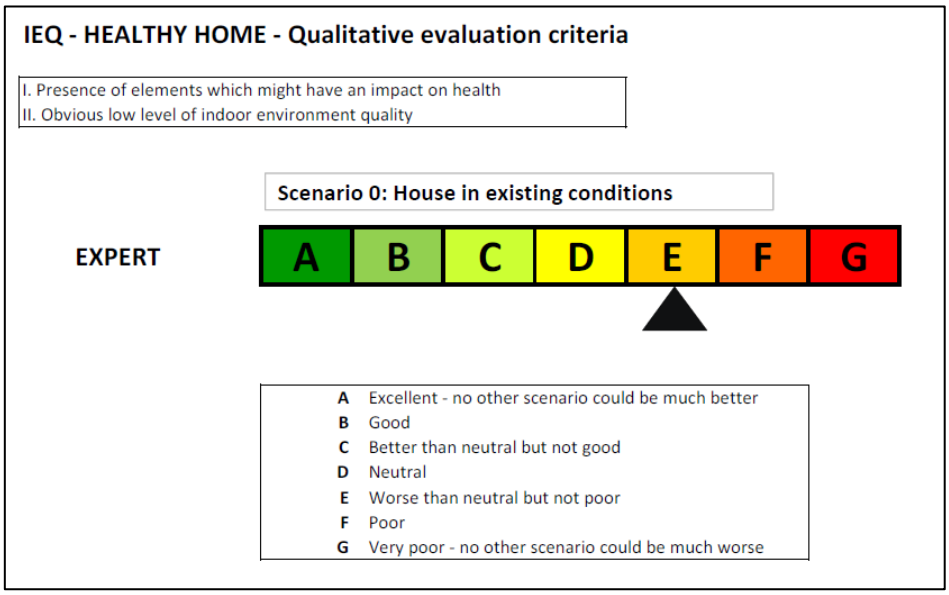


Figure 50: Building expert evaluation of the health conditions in the existing home for case study No. 1

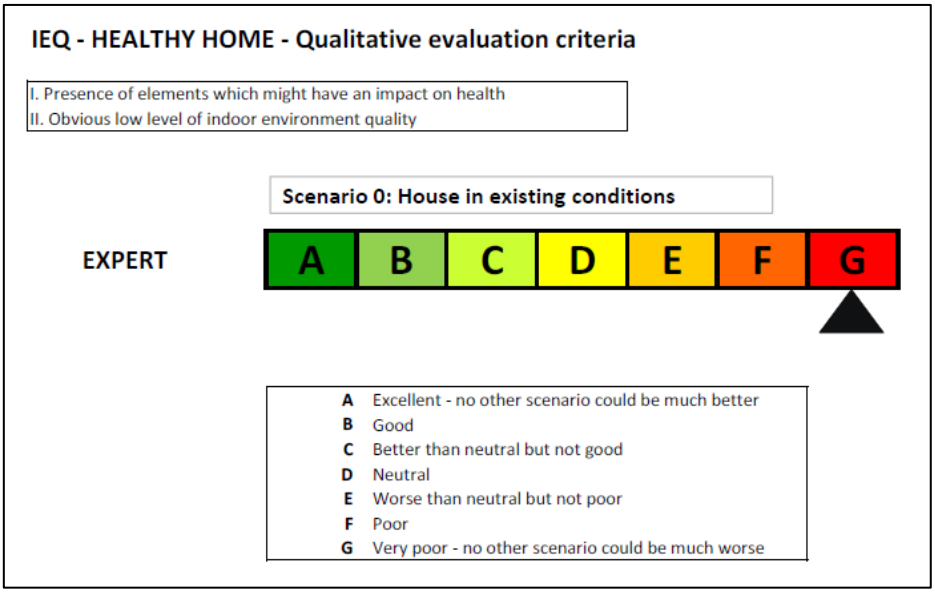


Figure 51: Building expert evaluation of the health conditions in the existing home for case study No. 2

In the same approach that for the previous criteria, the homeowners were asked to evaluate themselves the health conditions in the home in the existing conditions using the satisfaction scales (see Figure 52 for case study No. 1 and Figure 53 for case study No. 2).

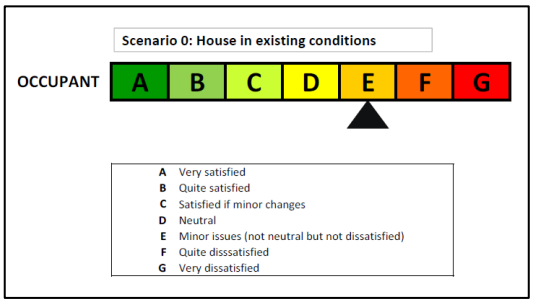


Figure 52: Evaluation of the health conditions in the home according to the homeowners of case study No. 1

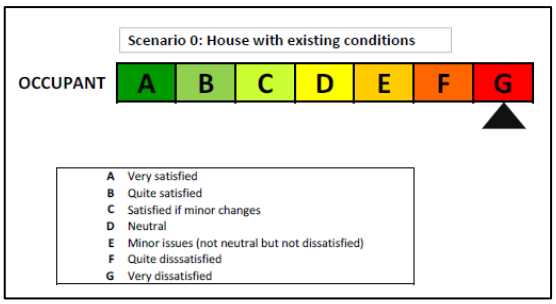


Figure 53: Evaluation of the health conditions in the home according to the homeowners of case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the health conditions in the home (see Figure 54 for case study No. 1 and Figure 55 for case study No. 2). The agreement between the parties one more time came naturally to an E evaluation “not neutral but not poor/not neutral but not dissatisfied” for case study No. 1 and to a G evaluation “Very poor / very dissatisfied” for case study No. 2.

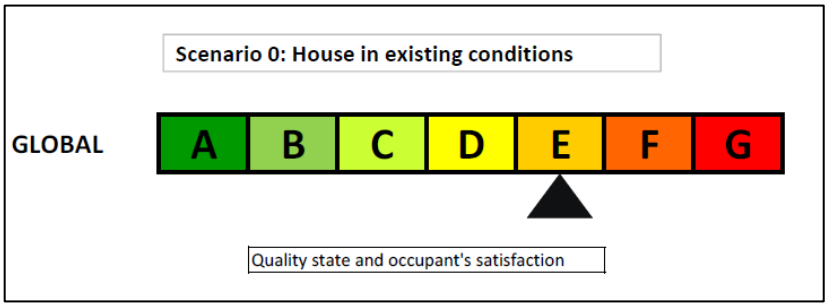


Figure 54: Global evaluation of the health conditions in the house for case study No. 1

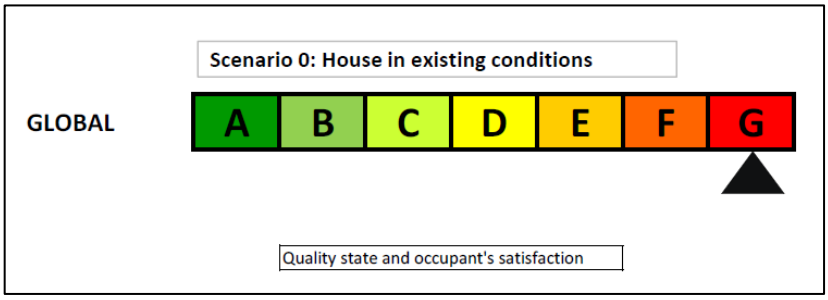


Figure 55: Global evaluation of the health conditions in the house for case study No. 2

2.4.4. Evaluation of the homeowners' immaterial values

The content of the immaterial values has been adapted for every household based on users' lifestyles, wishes, needs and sensitivities. The possible themes or criteria to be selected were the functionality, accessibility and spatial organization in the home; the aesthetic and artistic values; the preservation or modernization values; socio-cultural values; emotional or psychological values, and some specific values considered by the homeowners as important. Immaterial values are homeowner-specific values; they have therefore been evaluated by the homeowners themselves. The themes or criteria were presented, explained to the homeowners, pre-selected based on the homeowners' profiles (via the questionnaire, interviews and visualization of pictures) and finally evaluated by the homeowners thanks to the satisfaction scale. In the presence of an architect or an interior designer, some values could have been evaluated together with the expert.

The guiding sheet used by the building expert and the homeowners for the evaluation of the health conditions in the home included the main criteria selected based on the homeowners' profiles (see Figure 56 for case study No. 1 and Figure 57 for case study No. 2).

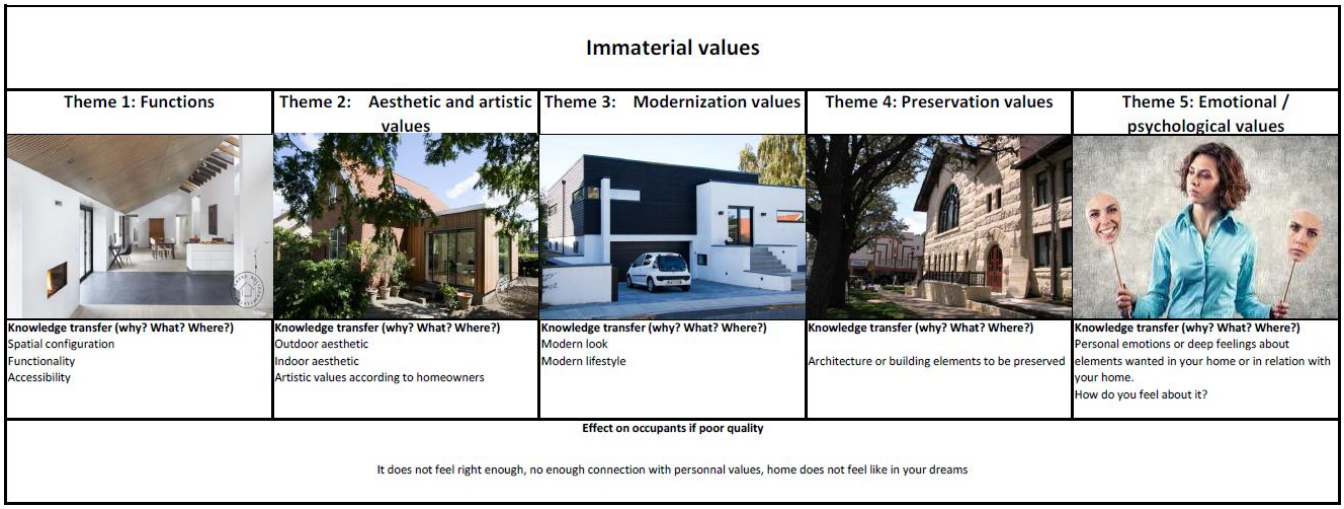


Figure 56: Themes or criteria selected and evaluated for case study No. 1. Sources of photographs: http://www.danskeboligarkitekter.dk/soeg/projekt/vis/lys-til-60er-parcelhus/#.UxRT3vldWxk, http://www.danskeboligarkitekter.dk/soeg/projekt/vis/energirenovering-gav-mere-lys-i-murermestervilla/#.UxRTD_ldWxk, Mathias Sønderskov Nielsen, http://staceylovenlife.wordpress.com/2013/10/16/emotional-intelligence, October 2013

Immaterial values			
Theme 1: Functions	**Theme 2: Aesthetic and artistic values**	**Theme 3: Modernization or preservation values**	**Theme 4: Diversity of materials**
			
Knowledge transfer (why? What? Where?) Spatial configuration Functionality Accessibility	**Knowledge transfer (why? What? Where?)** Outdoor aesthetic Indoor aesthetic Artistic values according to homeowners	**Knowledge transfer (why? What? Where?)** Modern look Modern lifestyle Elements to be preserved	**Knowledge transfer (why? What? Where?)** Theme brought by homeowners
Effect on occupants if poor quality It does not feel right enough, no enough connection with personnal values, home does not feel like in your dreams			

Figure 57: Themes or criteria selected and evaluated for case study No. 2. Sources of photographs: see figure 56 and http://www.completehome.com.au/suppliers/rock-n-stone/design-diversity-2, October 2013

2.4.4.1. Functionality, accessibility and spatial organization in the home

The following criteria dealt with the function of every room, loss of space in the house, and how well the diverse rooms could be used. Secondly with the accessibility needs such how accessible the home entrance is, how doors are placed in the house, access to first floor and garage, access to the terrace and to the garden usability of the kitchens and bathrooms. Thirdly, the theme dealt with the organization of the rooms and between rooms, and how much integrated the rooms were between each other. Also how adapted to the users the rooms were.

2.4.4.2. Aesthetic and artistic values

This criterion dealt with the diverse aesthetic and artistic values the homeowners found or did not find in their home. Examples of such values were the style of the façade, the type of roof, the colour of the windows, the type of flooring, etc.

2.4.4.3. Preservation or modernization values

The homeowners could either choose as a criterion preservation or modernization of their house or building elements or choose both values as two different criteria. Preservation is an endeavour that seeks to preserve, conserve and protect the building as it is or some elements of the building because it has a significance for the homeowners. Modernization can sometimes be in opposition with the fact of preserving. Indeed, some elements of the building could be replaced or transformed to be in a state closer to modern standards. Modernization can also complete preservation. Indeed some building elements can be preserved while other are modernized. Also some modern elements can be added into a building mostly preserved in its initial state. After discussion with the building expert, the homeowner of case study No. 1 decided to keep both criteria part of the decision making process since the homeowner did not find them contradictory. In case study No. 2, the homeowners selected only the modernization of the house as a criterion having enough weight to be part of the decision making.

2.4.4.4. Emotional / psychological and socio-cultural values

Real-world decision-making habitually implicates emotional, social or cultural considerations. Those values are of course decision maker specific which means in our case homeowners specific. Those values can relate for instance to previous experiences in the house, house inherited, memories, feelings relate to a specific culture, feeling of safety, etc. Those values came up during the conversation kept between the homeowners, the building expert and the process facilitator. They became a criterion when they could be clearly applied to the house in the existing conditions and to the possible evolution of those values for the house according to the possible renovation scenarios.

2.4.4.5. Diversity of materials

Diversity of materials is a criterion brought by the homeowners of the case study No. 2 house after discussion with the building expert. Even if it is a concept which could be part of the more general concept of artistic values, the homeowners decided that it was important enough for them to be a criterion by itself.

Immaterial values being homeowners specific, the corresponding criteria were evaluated by the homeowners alone, without any influence of the building expert. For the evaluation, the homeowners used the same evaluation scale than for the previous evaluations (see Figure 58). Results of the evaluation for the house in the existing conditions are presented in Figure 59 for case study No. 1 and Figure 60 for case study No. 2.

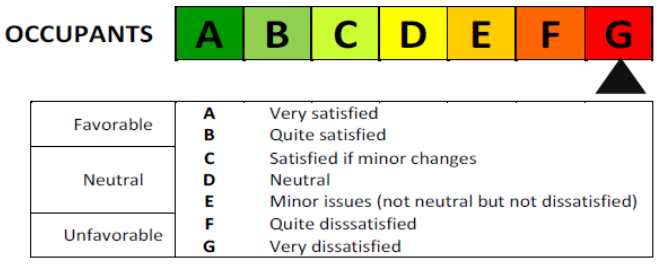


Figure 58: Evaluation scale used by the homeowners alone

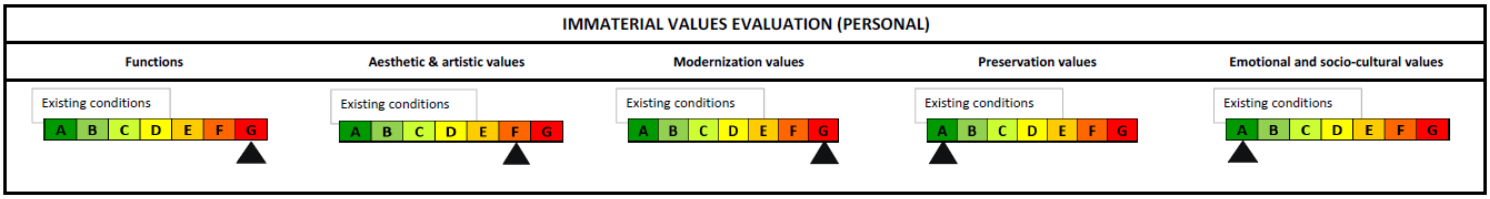


Figure 59: Evaluation of the immaterial values for case study No. 1

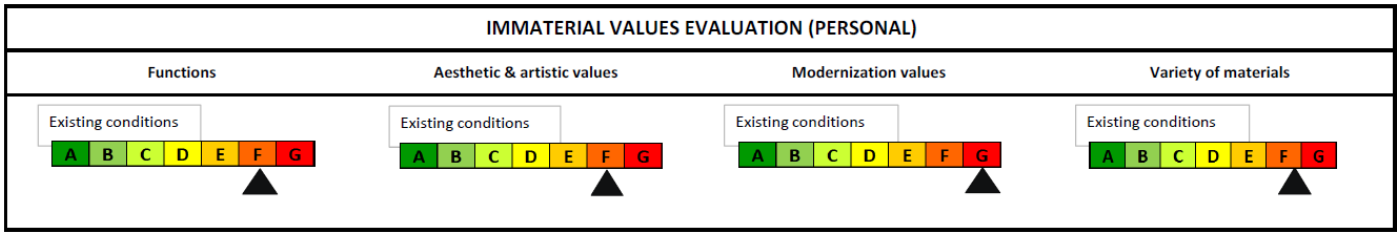


Figure 60: Evaluation of the immaterial values for case study No. 2

2.4.5. Evaluation of the economic situation of the homeowners

The evaluation of the economy was not done during the evaluation of the house in the existing conditions but only as a last step at the end of the evaluation of all potential renovation scenarios.

2.5. Generation of some renovation scenarios and selection of the most appropriate scenarios

The generation of the potentially selectable renovation scenarios has been based on the principle of suboptimisation: the well-being of an element is dependent on the well-being of the system of which it is a part. It is sometimes necessary for an element to limit its goals and actions in order to preserve the well-being of the system as a whole. In other words, acting to achieve a goal related to one performance criteria only may come to constrain other performance or quality criteria to the point of bringing a serious damage to the system as a whole. In that way, we have generated a series of renovation alternatives (+/- 20 alternatives). They are all cost-effective and at different levels of source energy saving. The alternatives are regrouped within 3 scenarios where most measures are the identical. This means that within the same scenario, alternatives distinguish themselves by a few measures only (e.g. scenario 1 with or without ventilation fans).

- ✓ All scenarios are based on the diagnosis of the house and evaluations of the criteria for the house in the existing conditions.
- ✓ All scenarios comply with or surpass the Danish regulation.
- ✓ All scenarios fulfil the need of a possible stepwise approach to renovation (step-by-step).
- ✓ All renovation alternatives regrouped with the 3 scenarios are cost-effective.

In this approach, cost-effective is defined as a positive total energy-related gain (see Figure 61 and Figure 62). The total energy-related gain is the difference between the gains resulting from the energy savings and the predicted market plus-value of the house subsequent from the improvement of the energy class, and the total cost of the energy-related measures. The longer the period is, the higher the total gain is, since every supplementary year brings supplementary energy savings. For the lowest periods considered in the calculations (5 and 10 years), the total energy-related gains reach their maxima before we the 100% source energy saving level. This means that the global cost of the energy-related measures for the renovation alternatives situated between the maximum and 100% of source energy saving, is not as compensated, by the gains resulting from the energy savings and the predicted market plus-value of the house from the improvement of the energy class, as for the other alternative giving a maximum of the total energy-related gain (around 79% of source energy saving for case study No. 1 and 70% for case study No. 2). For the longest considered periods (20 and 25 years for case study No. 1 and 15, 20 and 25 years for case study No. 2), the installation of photovoltaic panels allow to reach a maximum total energy-related gain at 100% of source energy saving.

- ✓ Following a multi-criteria building optimisation approach, the 3 scenarios bring increasing qualities and performance levels from scenario 1 to scenario 3.

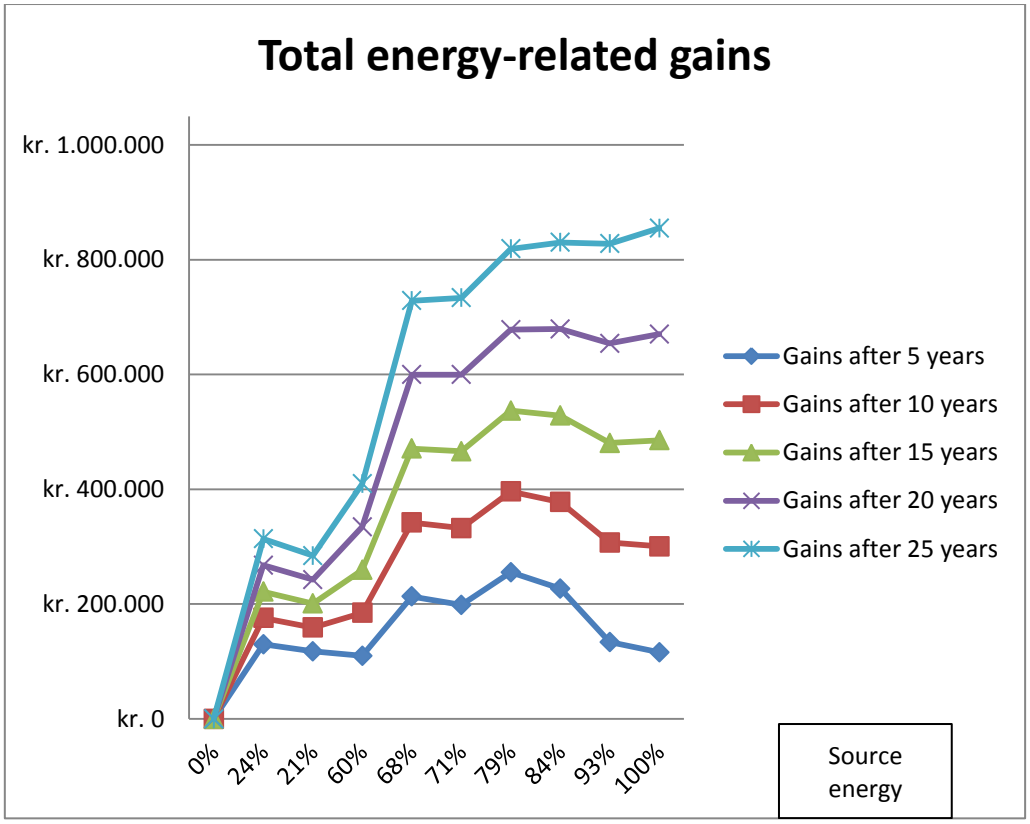


Figure 61: Total energy-related gains over diverse periods for case study No. 1

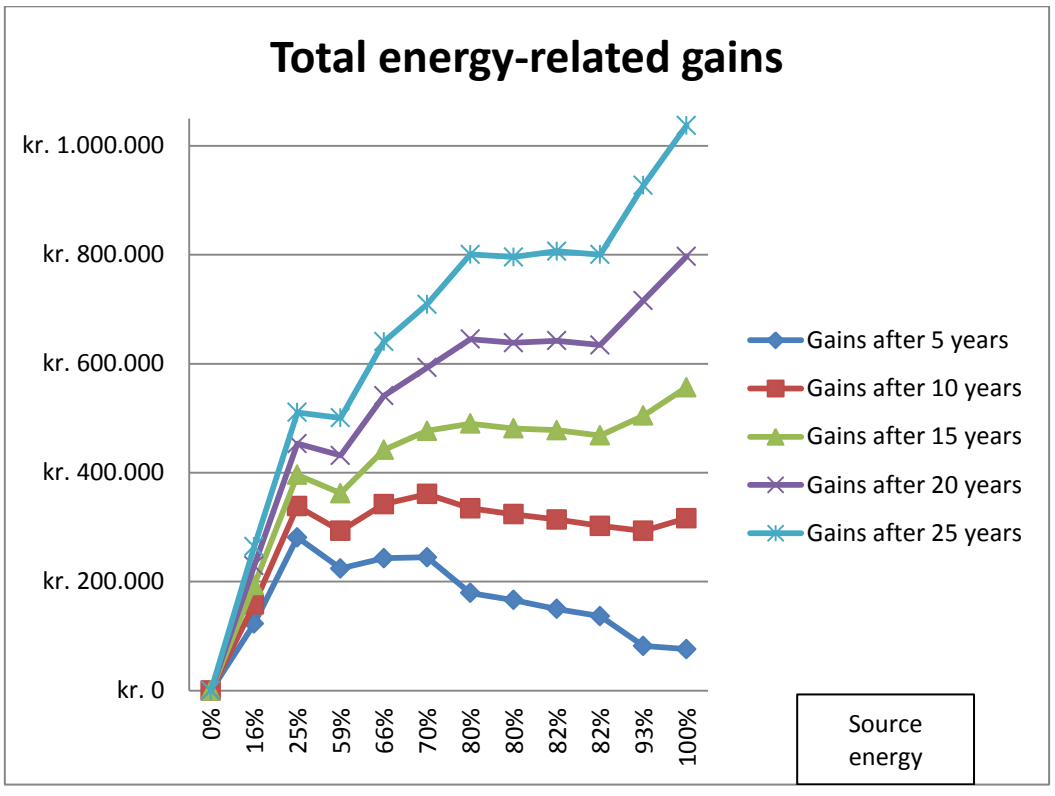


Figure 62: Total energy-related gains over diverse periods for case study No. 2

The scenarios bring improved quality states and increasing performance levels from scenario 1 to scenario 3. Within the 3 scenarios, the alternatives also bring increasing performance levels (especially in terms of energy performance and source energy saving). For case study No. 1 (No. 2), scenario 1 is divided into

alternatives 1.1 and 1.2 (1.1 and 1.2), scenario 2 is divided into alternatives 2.1, 2.2 and 2.3 (2.1, 2.2 and 2.3), and scenario 3 is divided into alternatives 3.1, 3.2, 3.3 and 3.4 (3.1, 3.2, 3.3, 3.4, 3.5, and 3.6). Alternatives within the same scenario are highlighted through the use of an "or" between the measures situated in the same column in the following table. They are presented and summarised as:

For case study No. 1:

RENOVATION SCENARIOS (AND ALTERNATIVES WITHIN EACH SCENARIO)		
SCENARIO 1	**SCENARIO 2**	**SCENARIO 3**

ENVELOPE		
New windows (Uw 1,65) [according to regulation]		New windows (Uw 0,80) [better than regulation]
Replacing the windows	Replacing and extending some of the windows	Transformation of window topology. Extension of terrace instead of garage corner
Minimum of improvement of general insulation and airtightness levels.	Insulation of the ground floor / basement ceiling & walls. Without floor heating system [according to regulation]	Insulation of the ground floor / basement ceiling & walls. With floor heating system [better than regulation]
	Exterior wall insulation + surface finish [according to regulation]	Exterior wall insulation + surface finish [better than regulation]
	Roof/ceiling insulation + surface finishing [according to regulation]	Roof/ceiling insulation + surface finish [better than regulation]
Thermal division between living space and garage (walls)		Demolition of the garage corner + roof in the south west direction + entrance hall via garage space
Basic insulation work between finished and unfinished space (1st floor)	Finished first floor [according to regulation or better]	Finished and extended first floor (see garage walls) [according to regulation or better]
	Acoustic insulation between ground and first floors	
Thermal division between basement and ground floor (new basement door)		Thermal division between basement and ground floor (sealing of basement) and extension of living space
		Removal of entrance doors + access via garage

TECHNICAL INSTALLATIONS		
Update of heating control	New heating control	New hybrid heating control
Improvement of plumbing installations (where accessible)		New plumbing installations
Improvement of electrical installations (where accessible)		New electrical installations

Insulation of hot water piping		
Ventilation extractors (toilet, bathroom and kitchen) (alt. 1.2) **or**,		
No extractor (alt. 1.1)	Double flow mechanical ventilation with heat recovery	
Refurbishment of oil boiler	Air source heat pump + integration work	
	Removal of electrical water heater	
	No solar water heater **or**,	
	Solar water heater with +/- 3 m2 of panels + adapted hot water cylinder **or**,	
	Solar water heater with +/- 6 m2 of panels + adapted hot water cylinder	
		No photovoltaic panel (solar electricity production) **or**,
		Including 2.5 KW of photovoltaic panels + related components (converter, etc.) **or**,
		Including 4 KW of photovoltaic panels + related components (converter, etc.)

INTERIOR & GENERAL REPAIR		
General repair and new upgrades	New set-up	
	New drains (basement walls)	
		New ground floor (incl. extended area from entrance hall, installations room, garage corner)
	Use of first floor (limited space)	New first floor (incl. extended area from garage and staircase)
	Semi-open spaces	Open spaces
	Improvement of bathroom	Extended and new bathroom
	Improvement of kitchen	Extended and new kitchen

And for case study No. 2:

ENVELOPE		
Windows (Uw 2,7) (alt. 1.1) or,		
Windows (Uw 1,65) (alt. 1.2) [according to regulation]		Replacing the windows (Uw 0,80) [better than regulation]
Replacing the windows	Large window areas	
Minimum of improvement of general insulation and airtightness levels.	Insulation of the ground floor / basement / crawl space ceiling + walls without floor heating system [according to regulation]	Insulation of the ground floor / basement / crawl space ceiling + walls with floor heating system [better than regulation]
	Exterior wall insulation + surface finish [according to regulation]	Exterior wall insulation + surface finish [better than regulation]
	Roof/ceiling/terrace insulation + surface finishing [according to regulation]	Roof/ceiling/terrace insulation + surface finish [better than regulation]
Cavity wall insulation		
Thermal division between living space and garage (walls)	Demolition of the wing building east side and first floor (roof)	
Basic insulation work between finished and unfinished space (1st floor)	Dismounting of roof and new first floor [according to regulation or better]	
Thermal division between basement and ground floor (new basement door)		

TECHNICAL INSTALLATIONS		
Update of heating control	New heating control	New hybrid heating control
Improvement of plumbing installations (where accessible)		New plumbing installations
Improvement of electrical installations (where accessible)		New electrical installations
Insulation of hot water piping		
Ventilation extractors (toilet, bathroom and kitchen) or,		
	Double flow mechanical ventilation with heat recovery	
Oil boiler remains as it is	Air source heat pump + integration work or,	
	Ground source heat pump + integration work	
	No solar water heater or,	
	Solar water heater with +/- 3 m2 of panels + adapted hot water cylinder or,	
	Solar water heater with +/- 6 m2 of panels + adapted hot water cylinder	
		No PV panel + related components or,

		Including 2.0 KWp of PV panels + related components (converter, etc.) or,
		Including 3.5 KWp of PV panels + related components (converter, etc.)

INTERIOR & GENERAL REPAIR		
General repair and new upgrades	New set-up and new first floor	
	New drains (basement walls)	
	Open spaces	
	Improvement of bathroom	Extended and new bathroom
	Improvement of kitchen	Extended and new kitchen

2.6. Evaluations for the building according to the pre-selected renovation scenarios

As for the evaluation of the house in the existing conditions (before renovation), the house in all the pre-selected renovation scenarios was also evaluated. For each scenario, it was presented to the homeowners how the effects they had experienced could be reduced or eliminated. It was also explained how these renovation scenarios could fulfil their wishes and expectations.

2.6.1. Evaluation of the technical aspects

All technical aspects were all uniquely treated by the building expert. The evaluations were all expert knowledge based. The same 7 item evaluation scales was used, qualitative for the degradation state and for the technical obsolescence (see Figure 11) and quantitative (aligned to the BR10 Danish energy label scale) for the energy performance of the building (see Figure 13).

2.6.1.1. Degradation state and technical obsolescence

In the same approach than for the house in the existing conditions, the expert evaluated the state of degradation and of technical obsolescence of the upgraded building components. The building expert then aggregated the results in his mind to give a global state of degradation and of technical obsolescence for the house as a whole. The building expert obtained the following results for the pre-selected renovation scenarios (Figure 63 for case study No. 1 and Figure 64 for case study No. 2). In scenarios 1, the building expert tried to get the house degradation state and technical obsolescence outside the critical or unfavourable zone through a minor renovation of the house (limited budget). The condition of starting with a minor renovation was that it should not hinder the possibility of undertaking a major renovation in the future, this without working on the same types of measures twice, and therefore without having the same costs multiplied. It worked for both case study houses but not entirely for the technical obsolescence state of the case study No. 2 house. Indeed, a minor renovation would not allow the upgrade of some of the updated building components and replacing some of the components would have led to the impossibility to undertake deep renovation measures in the future. The two major renovation scenarios (scenarios 2 and 3) both brought the degradation state of the house and the technical obsolescence of the building components to a favourable state.

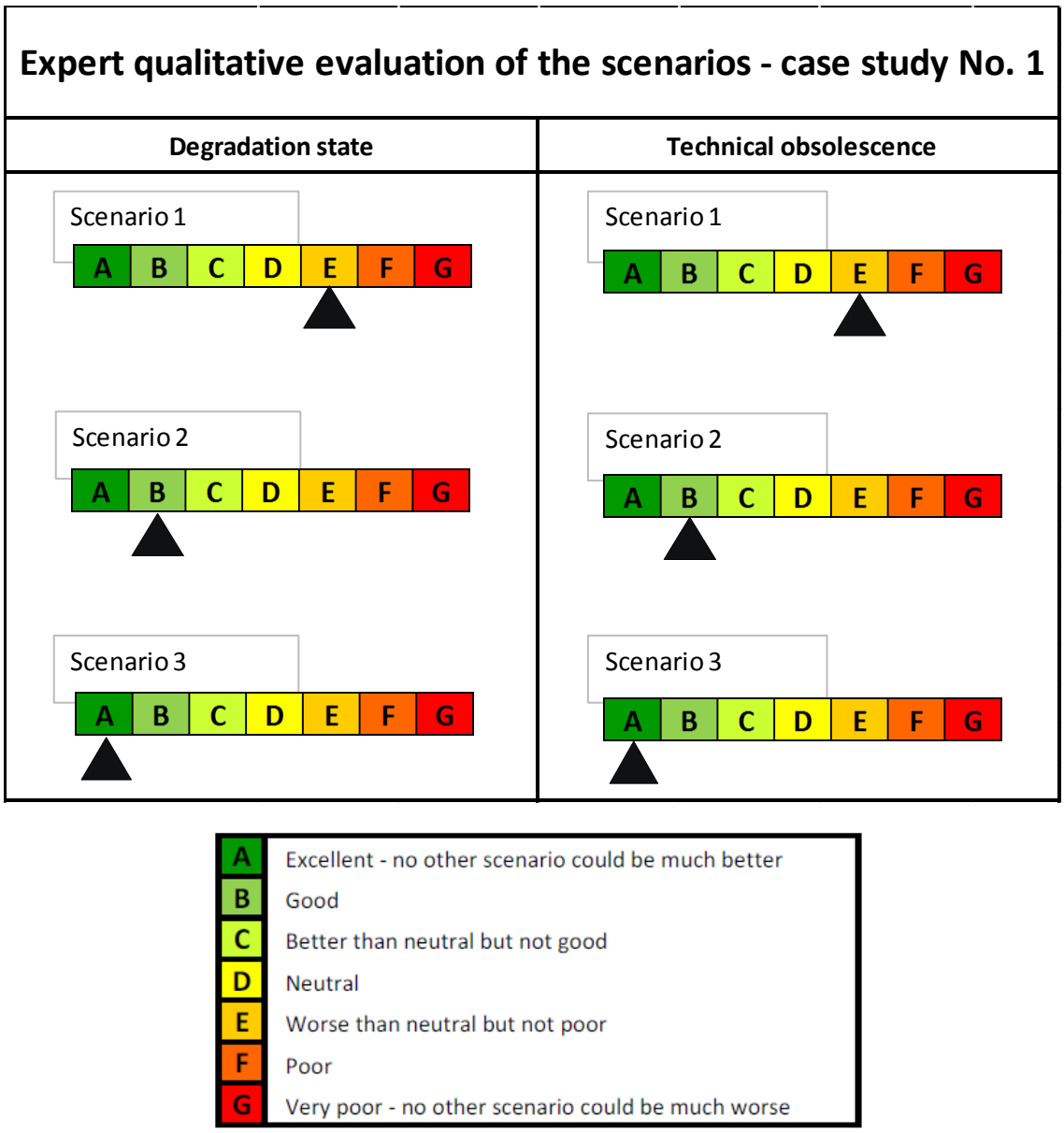


Figure 63: Expert qualitative evaluation of the scenarios for case study No. 1

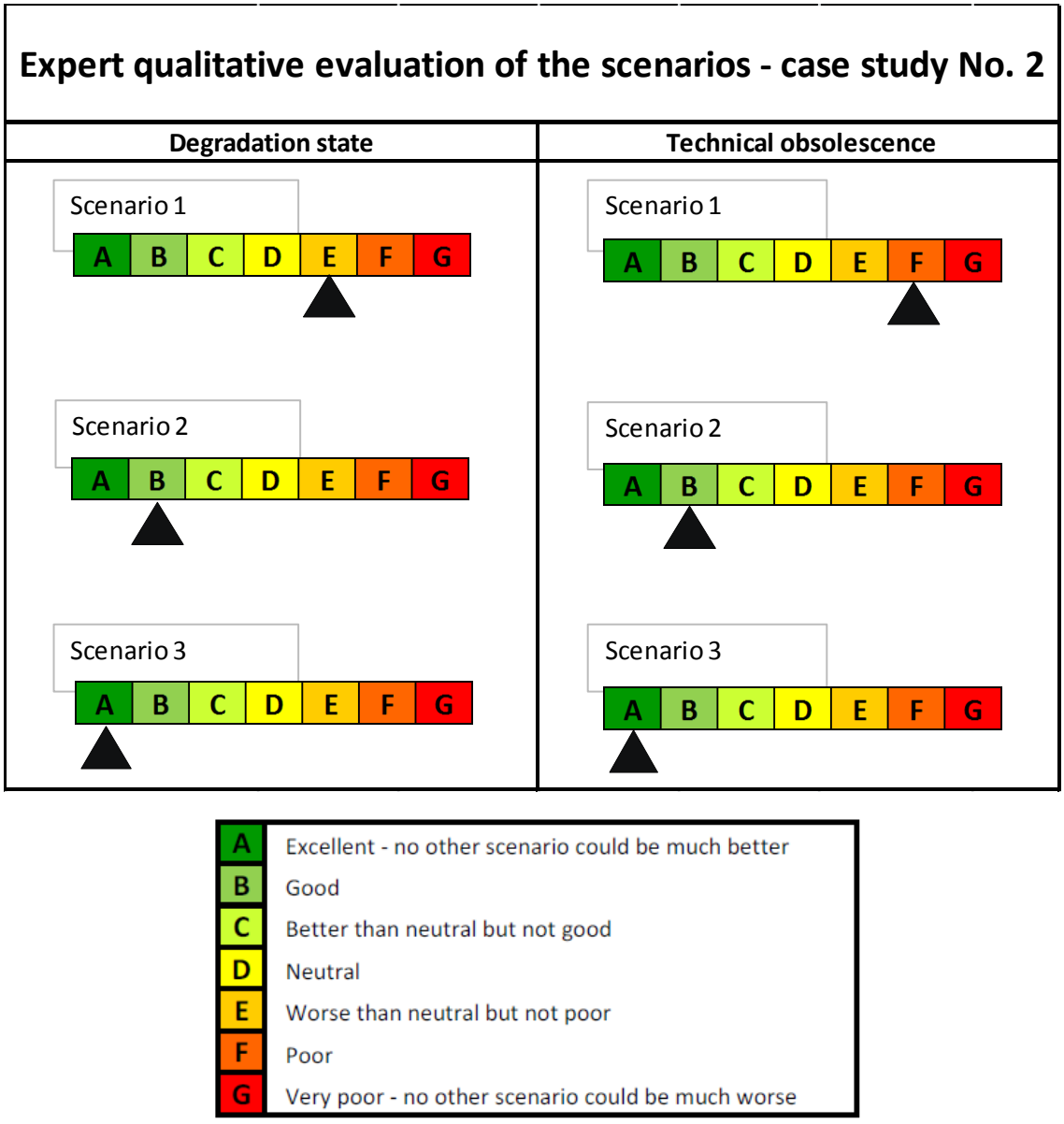


Figure 64: Expert qualitative evaluation of the scenarios for case study No. 2

2.6.1.2. Energy performance of the building

The energy performance of the building was quantitatively evaluated via building simulations ran in BEopt. The engine used was EnergyPlus version 8.1. A model of the house was done for each house and each scenario. Alternatives were obtained thanks to the optimisation module of BEopt. The results are given for both all the renovation scenarios for both case studies (see Figure 65 and Figure 66).

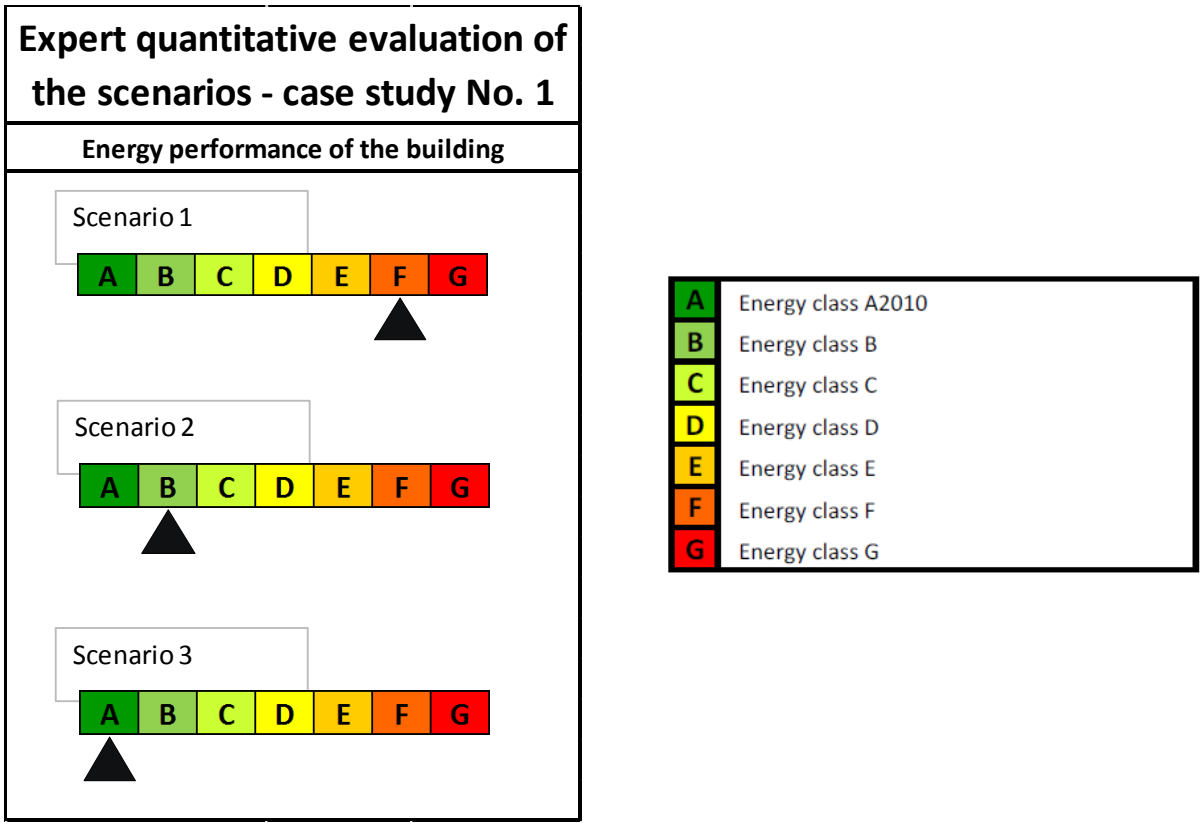


Figure 65: Expert quantitative evaluation of the scenarios for case study No. 1

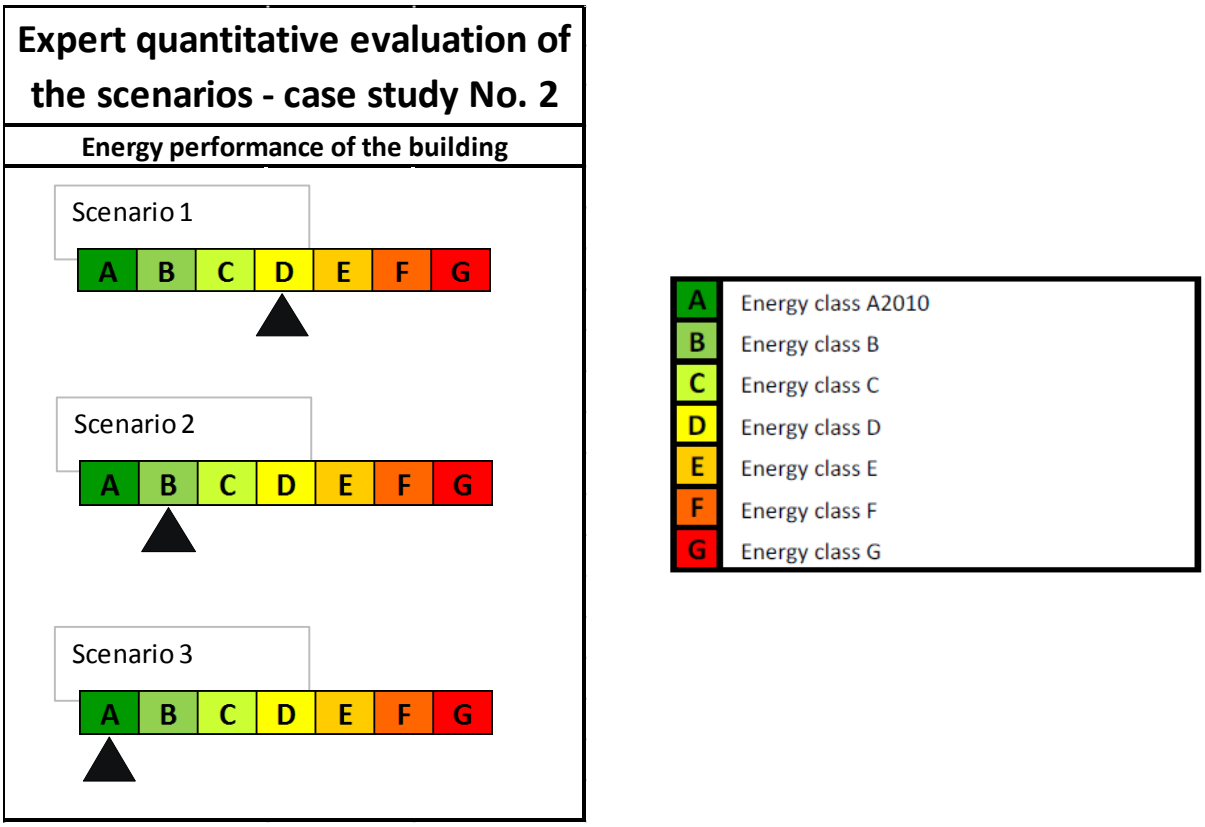


Figure 66: Expert quantitative evaluation of the scenarios for case study No. 2

2.6.2. Other evaluations

2.6.2.1. Indoor environment quality of the house

The evaluation of the indoor environment quality of the renovation scenarios has been based on the same themes used for the evaluation of the house in the existing conditions. For each theme, the building expert discussed with the homeowners, presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not, and how. After exchange of knowledge, the building expert presented the results of his own evaluation. Then, the homeowners were asked to evaluate the same theme using the satisfaction scale. Finally, the building expert and the homeowners agreed on the results.

2.6.2.1.1. Thermal comfort

The evaluation of the thermal comfort done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 67 for case study No. 1 and Figure 68 for case study No. 2).

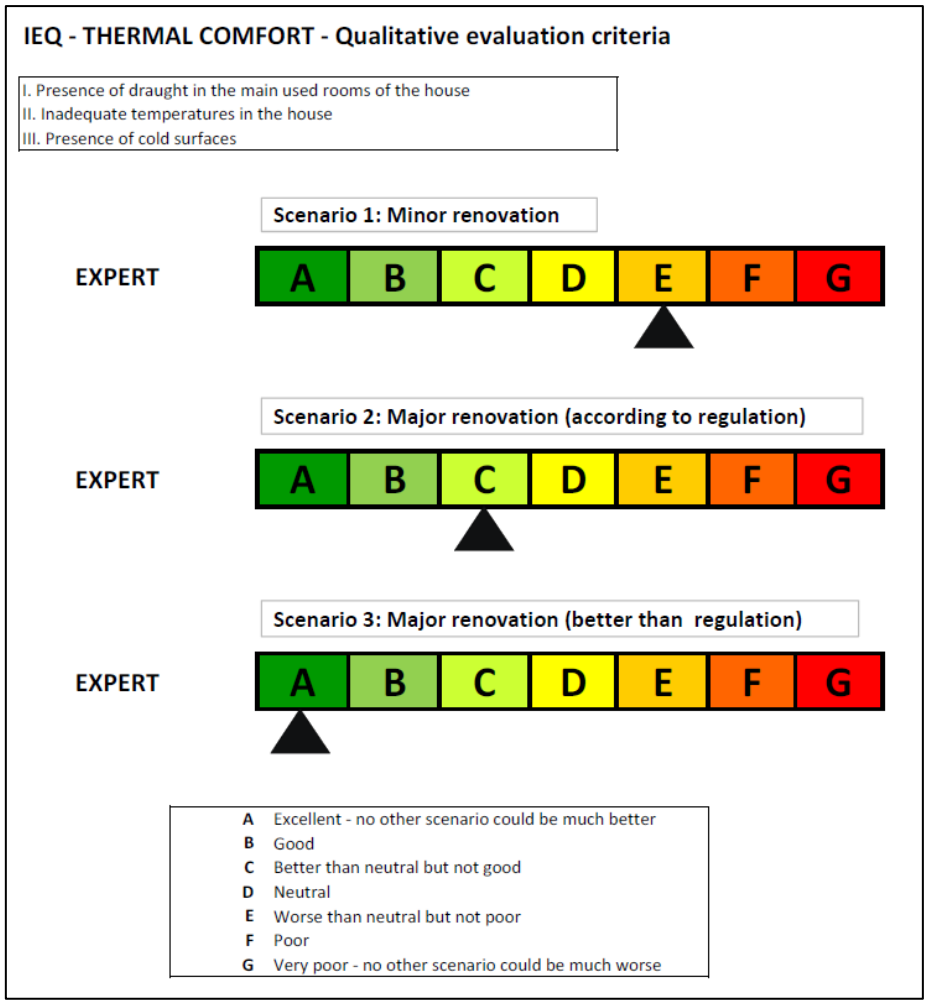


Figure 67: Building expert evaluation of the thermal comfort of the pre-selected scenarios for case study No. 1

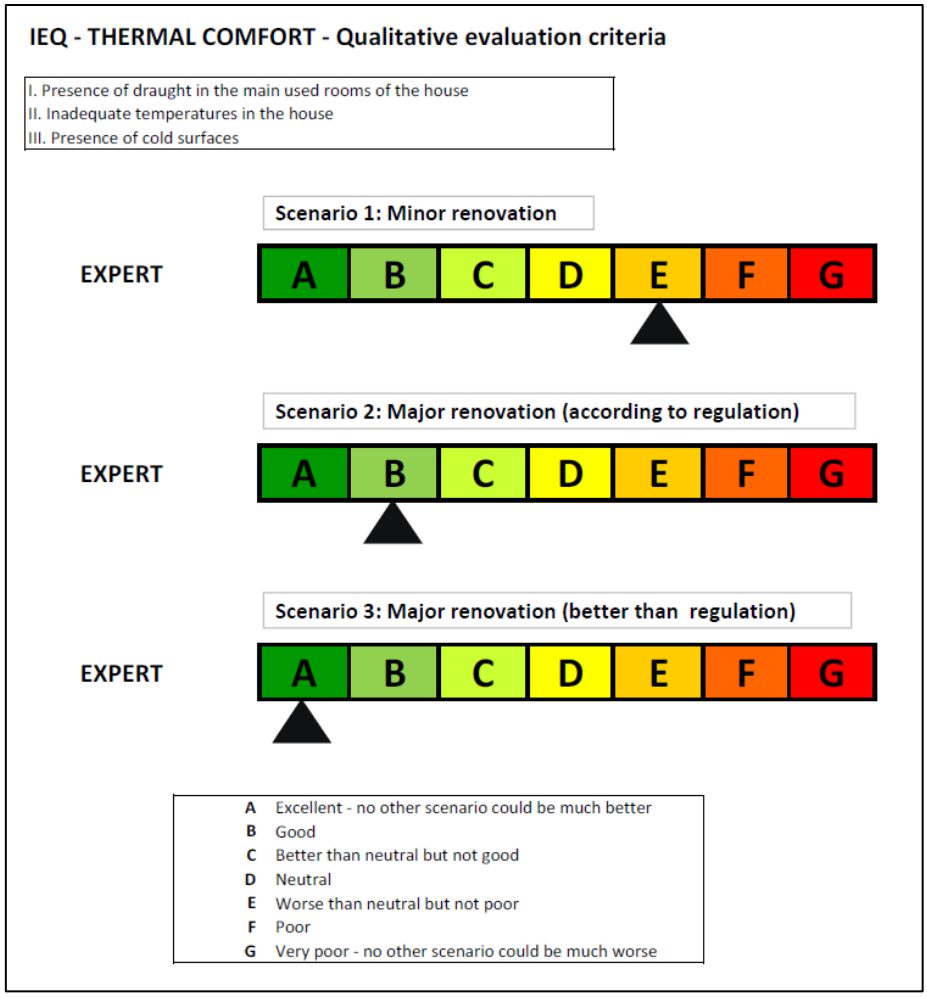


Figure 68: Building expert evaluation of the thermal comfort of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the thermal comfort of their house using the satisfaction scales for the pre-selected scenarios (see Figure 69 for case study No. 1 and Figure 70 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of thermal comfort.

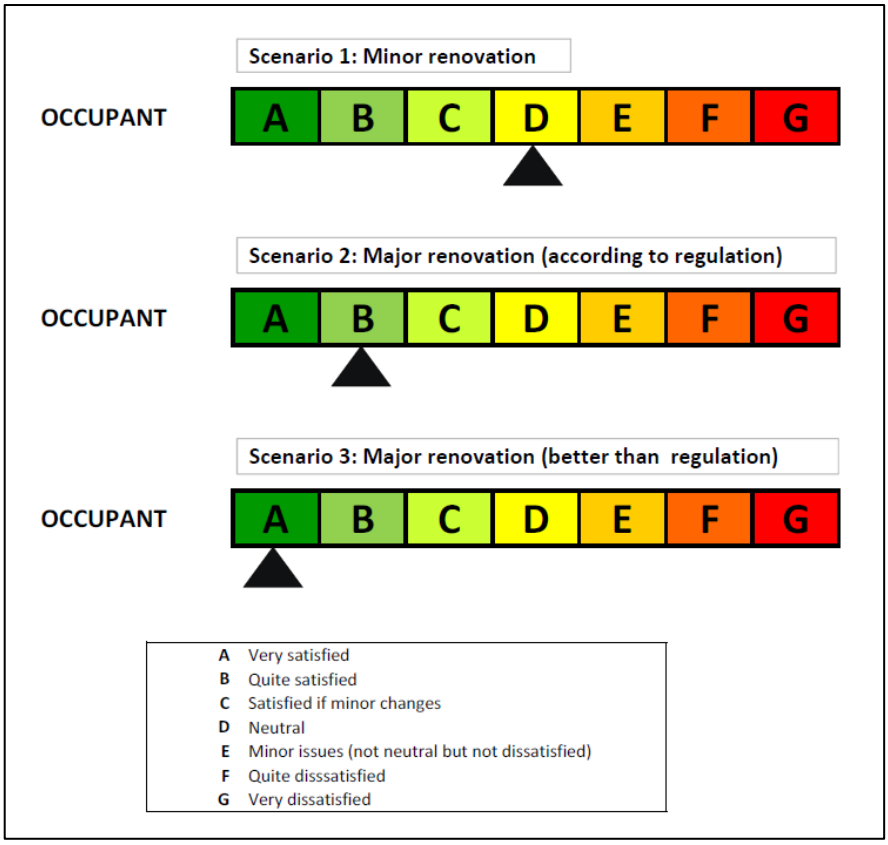


Figure 69: Homeowners' evaluation of the thermal comfort of the pre-selected scenarios for case study No. 1

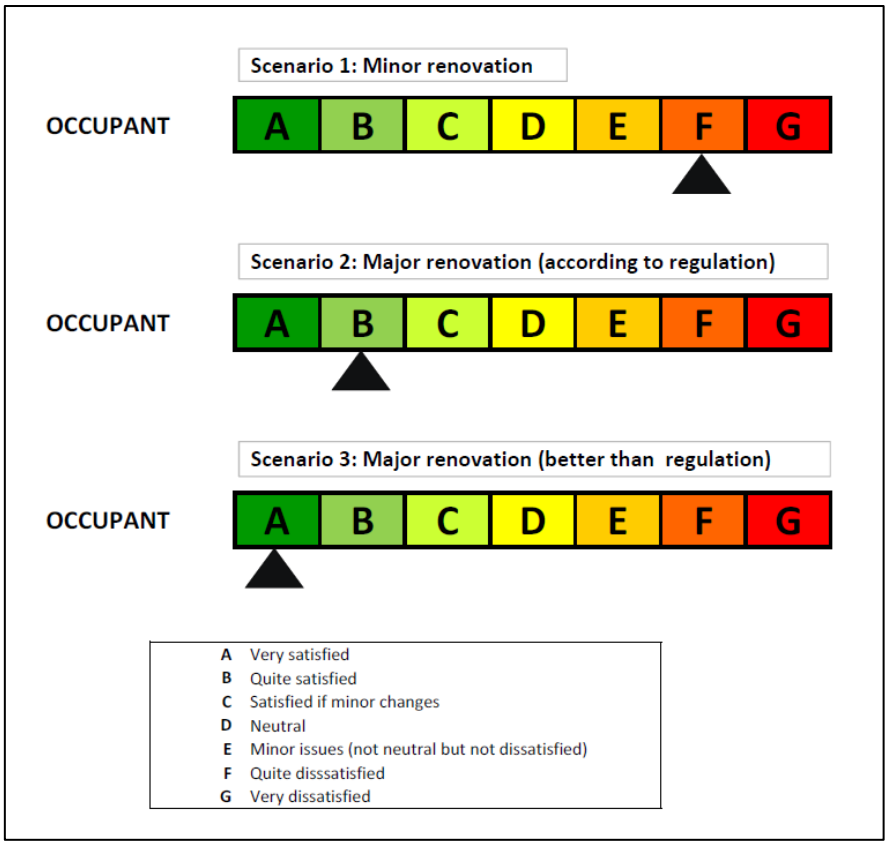


Figure 70: Homeowners' evaluation of the thermal comfort of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the thermal comfort, the results are as

follow (see Figure 71 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

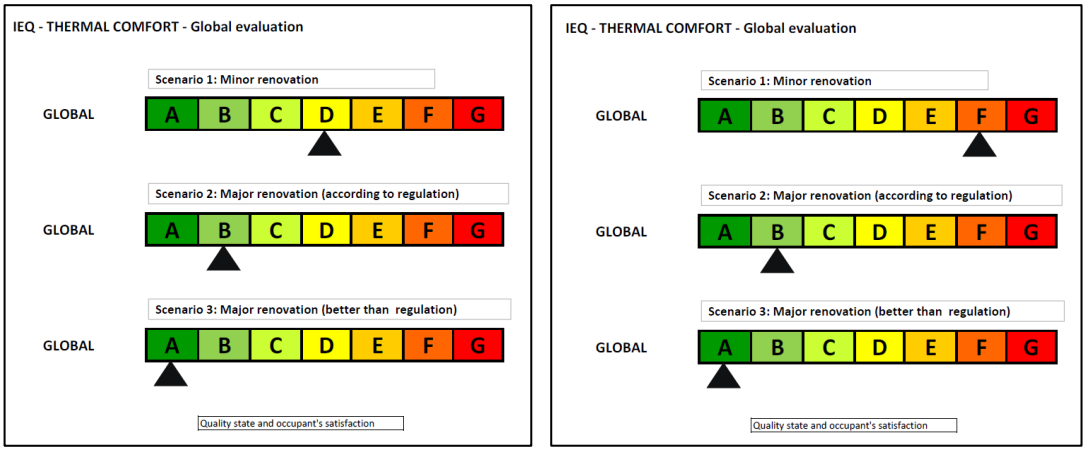


Figure 71: Global evaluation of the thermal comfort quality of case studies No. 1 and No. 2

2.6.2.1.2. Indoor air quality

The evaluation of the indoor air quality done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 72 for case study No. 1 and Figure 73 for case study No. 2).

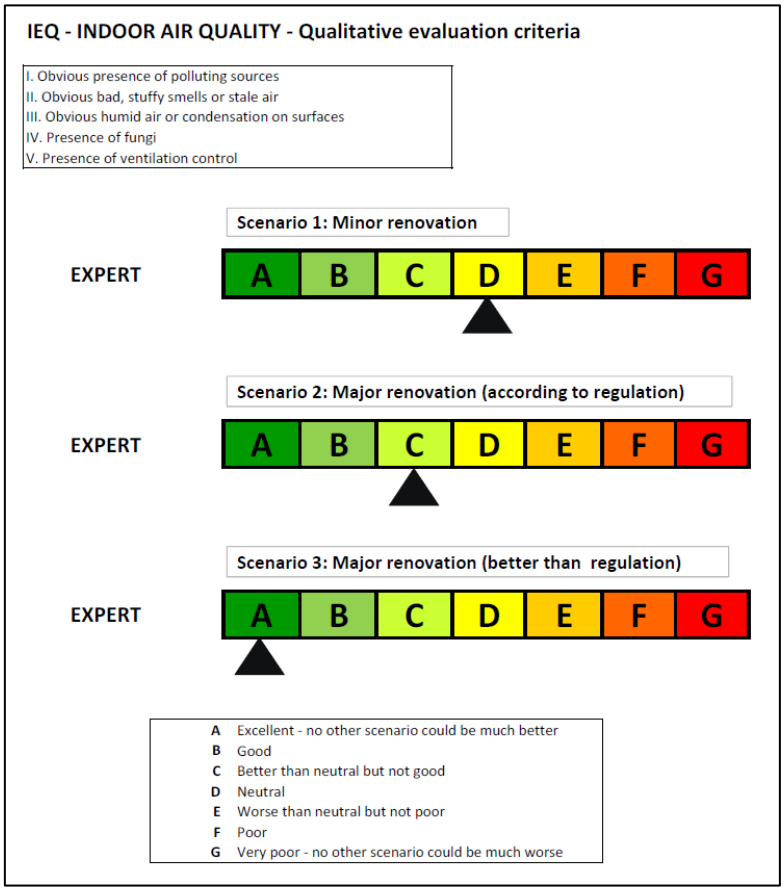


Figure 72: Building expert evaluation of the indoor air quality of the pre-selected scenarios for case study No. 1

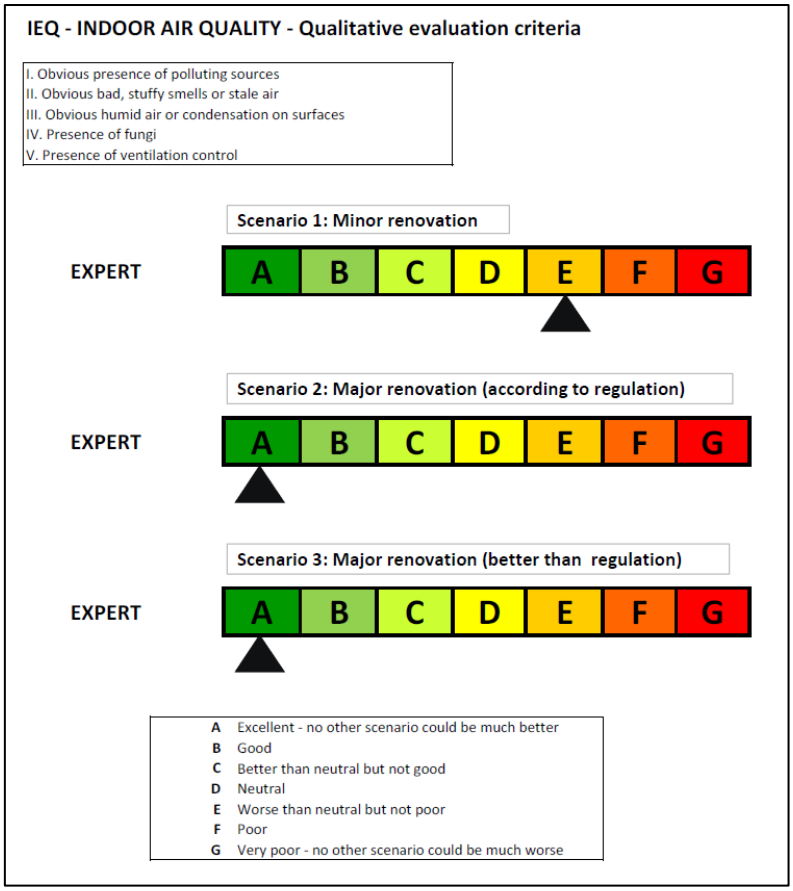


Figure 73: Building expert evaluation of the indoor air quality of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the indoor air quality of their house using the satisfaction scales for the pre-selected scenarios (see Figure 74 for case study No. 1 and Figure 75 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of indoor air quality.

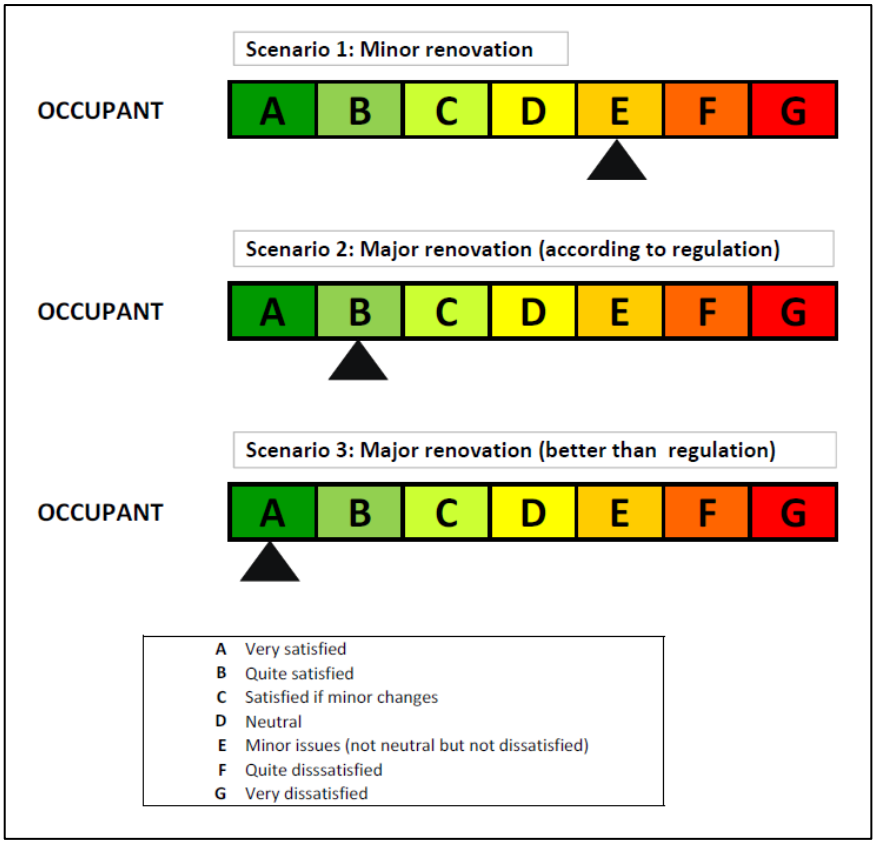


Figure 74: Homeowners' evaluation of the indoor air quality of the pre-selected scenarios for case study No. 1

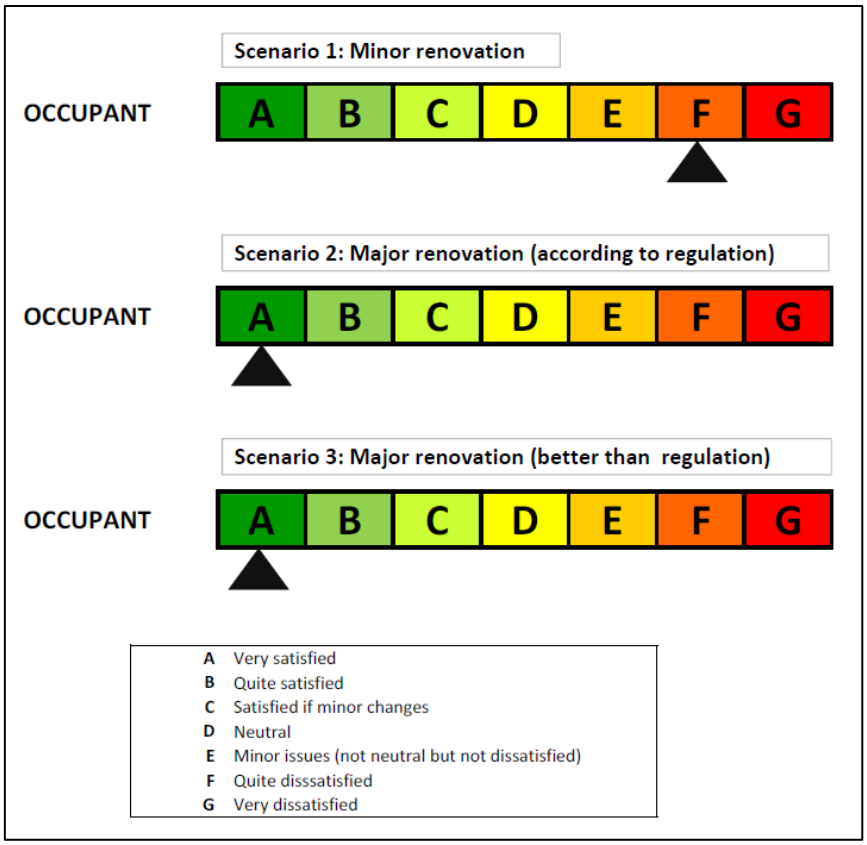


Figure 75: Homeowners' evaluation of the indoor air quality of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the indoor air quality, the results are as

follow (see Figure 76 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

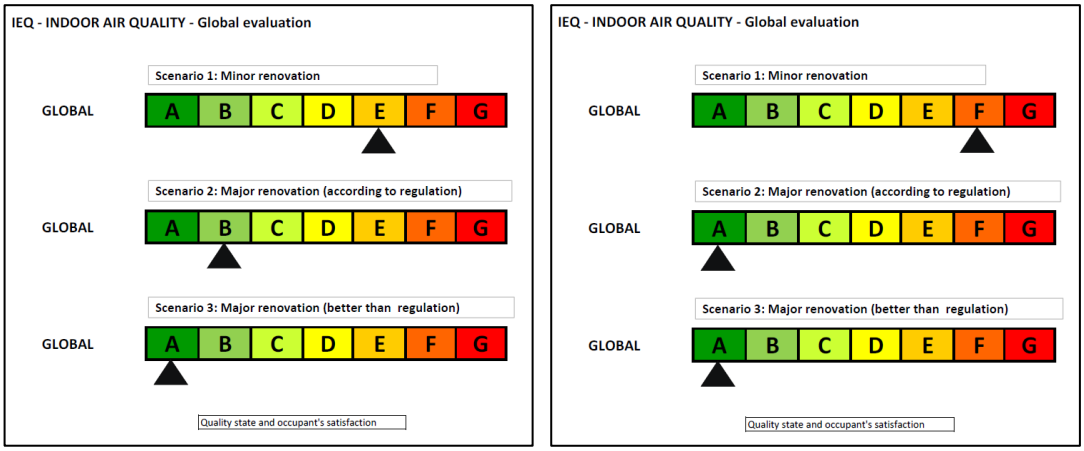


Figure 76: Global evaluation of the indoor air quality of case studies No. 1 and No. 2

2.6.2.1.3. Visual comfort

The evaluation of the visual comfort done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 77 for case study No. 1 and Figure 78 for case study No. 2).

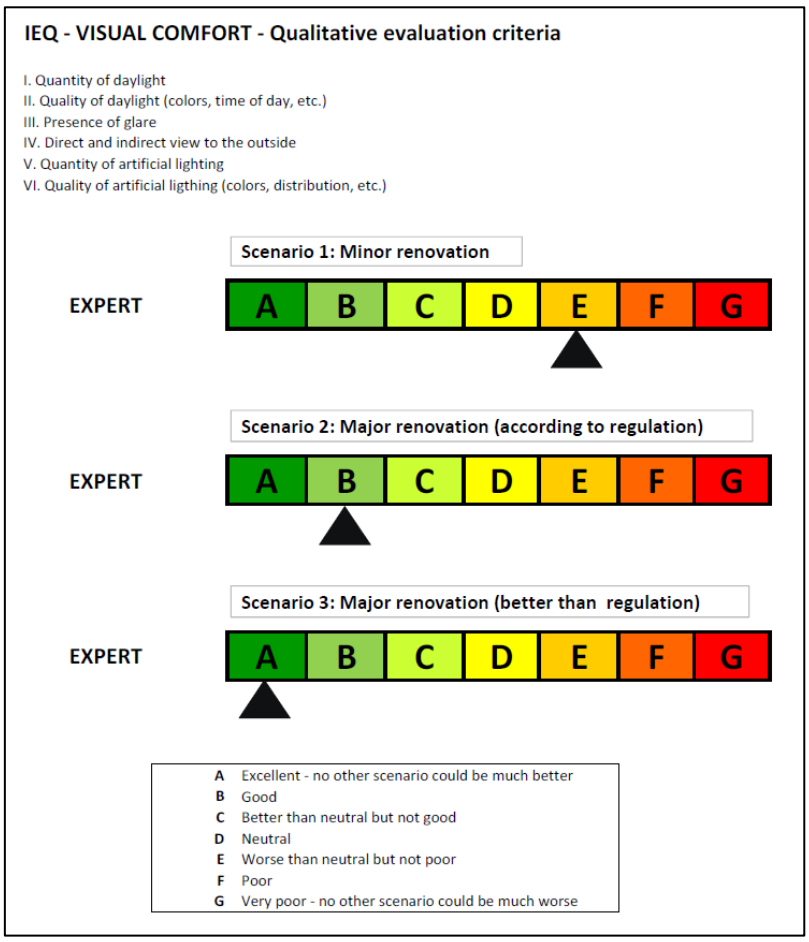


Figure 77: Building expert evaluation of the visual comfort of the pre-selected scenarios for case study No. 1

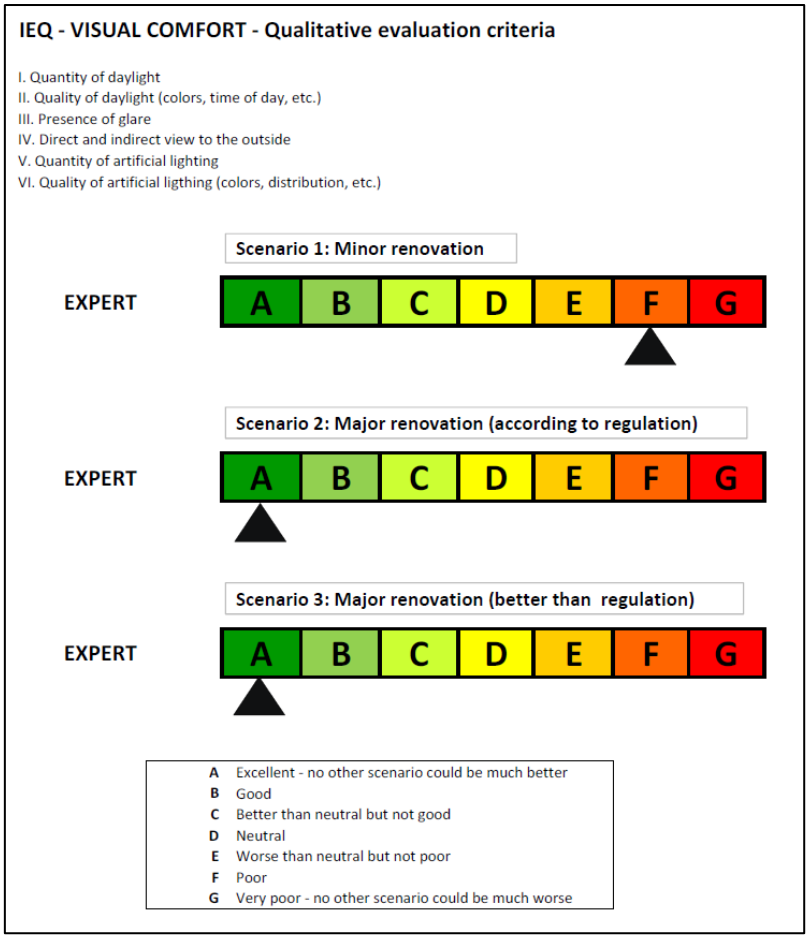


Figure 78: Building expert evaluation of the visual comfort of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the visual comfort of their house using the satisfaction scales for the pre-selected scenarios (see Figure 79 for case study No. 1 and Figure 80 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. Because there were more sub-criteria in the evaluation of the visual comfort, the homeowners preferred to evaluate each theme at the time before giving an evaluation for the whole criteria of visual comfort.

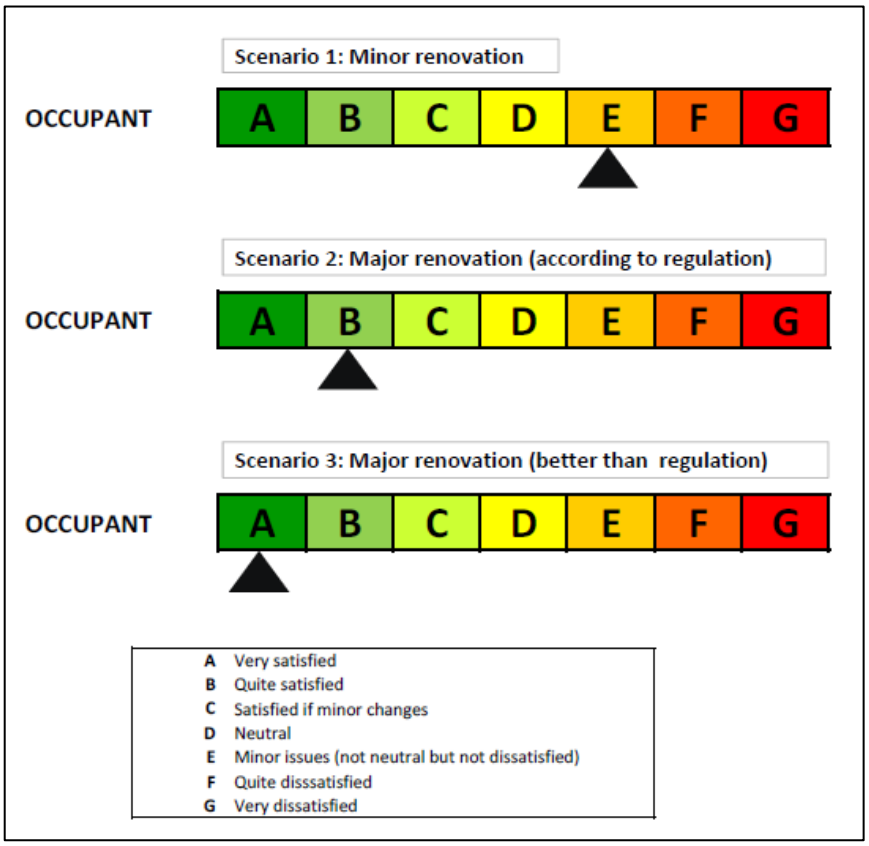


Figure 79: Homeowners' evaluation of visual comfort of the pre-selected scenarios for case study No. 1

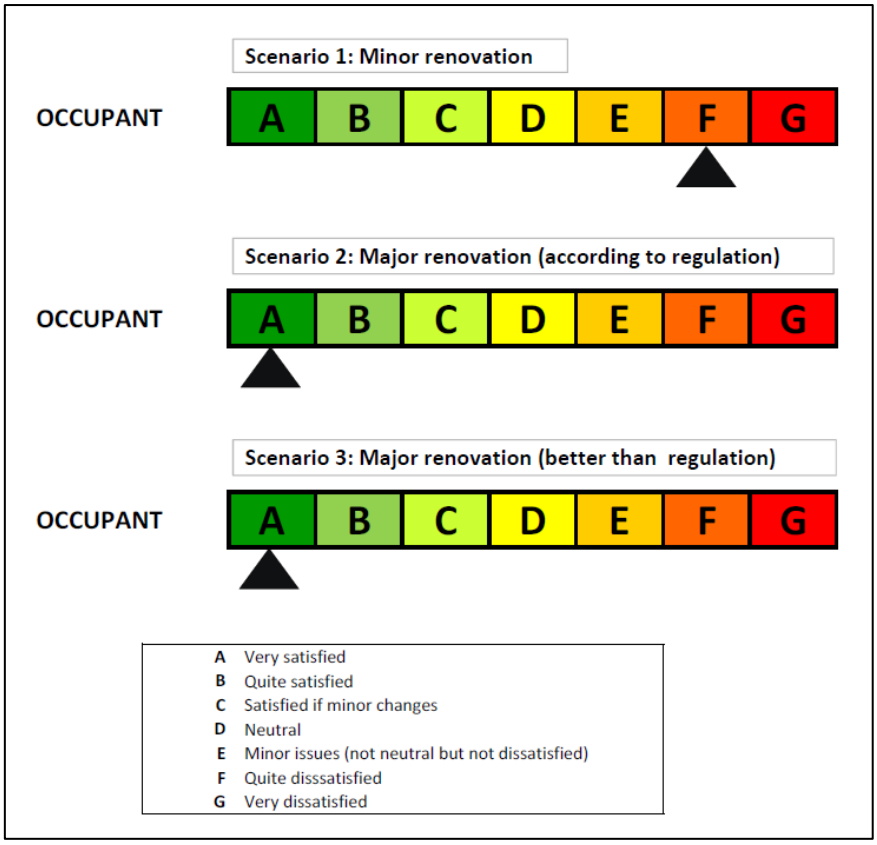


Figure 80: Homeowners' evaluation of the visual comfort of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the visual comfort, the results are as follow (see Figure 81 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

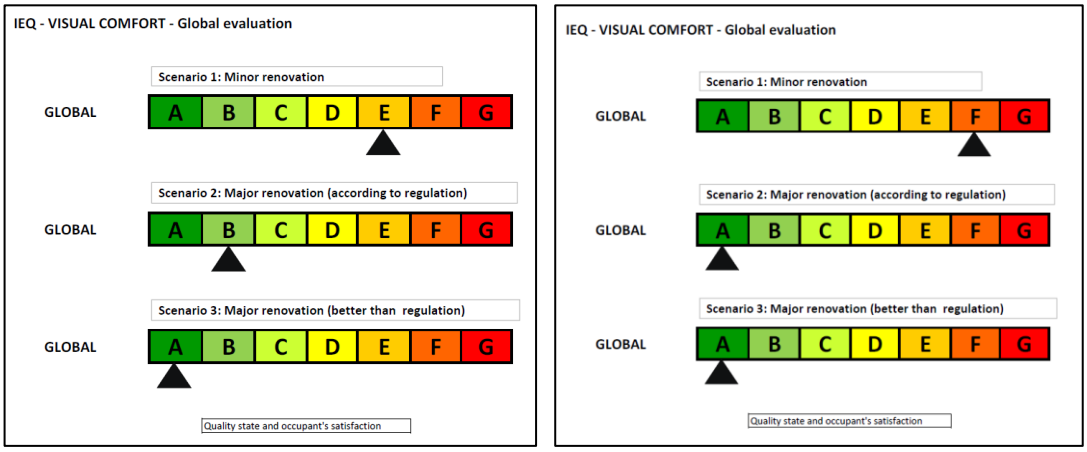


Figure 81: Global evaluation of the visual comfort of case studies No. 1 and No. 2

2.6.2.1.4. Acoustic comfort

The evaluation of the acoustic comfort done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 82 for case study No. 1 and Figure 83 for case study No. 2).

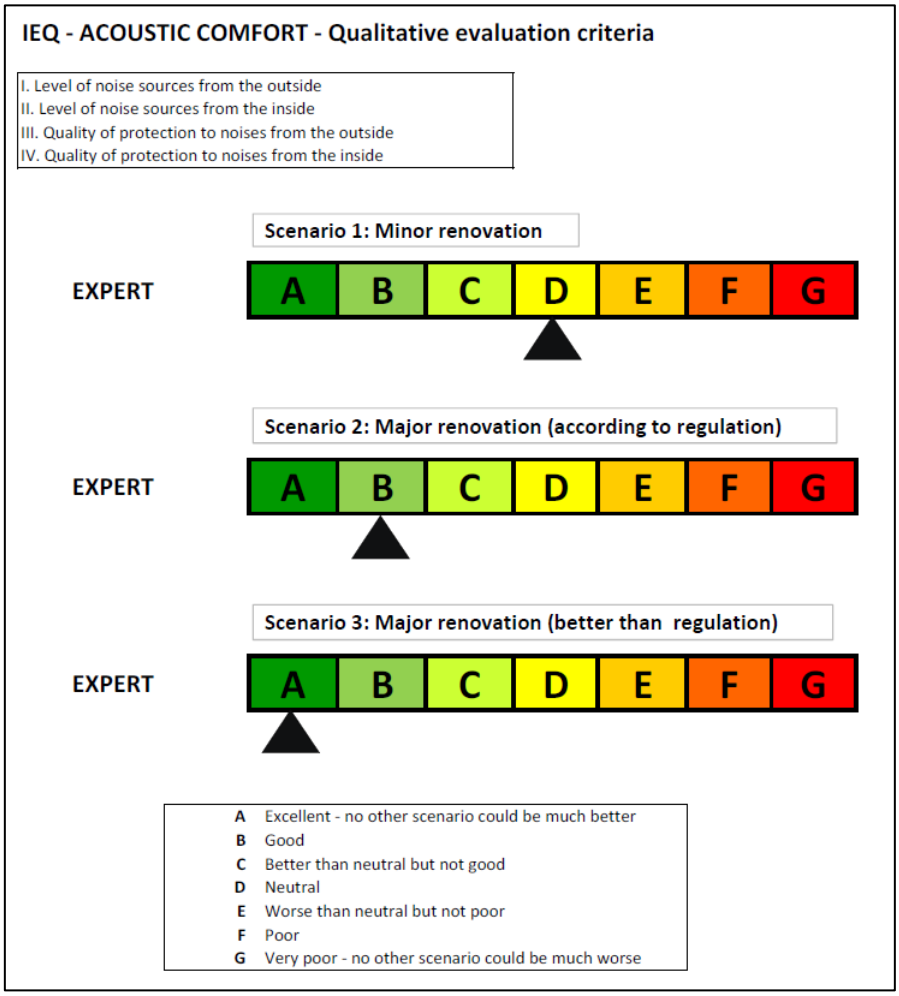


Figure 82: Building expert evaluation of the acoustic comfort of the pre-selected scenarios for case study No. 1

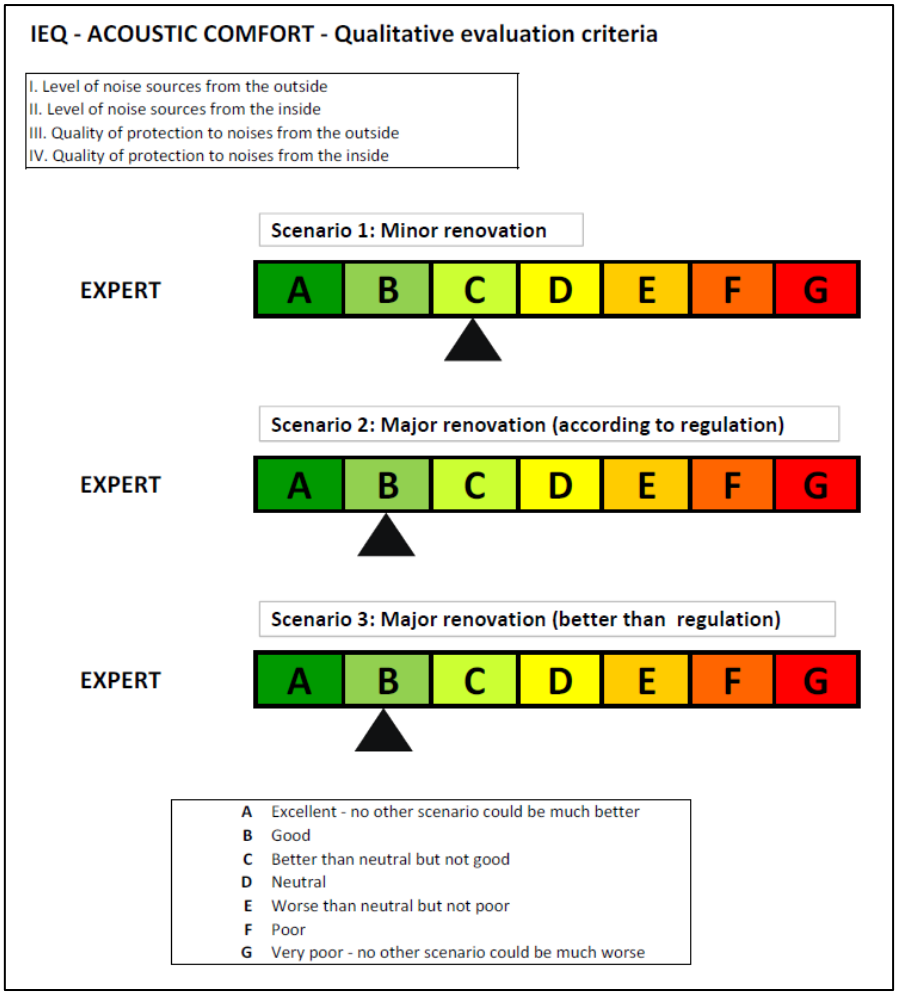


Figure 83: Building expert evaluation of the acoustic comfort of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the acoustic comfort of their house using the satisfaction scales for the pre-selected scenarios (see Figure 84 for case study No. 1 and Figure 85 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of acoustic comfort.

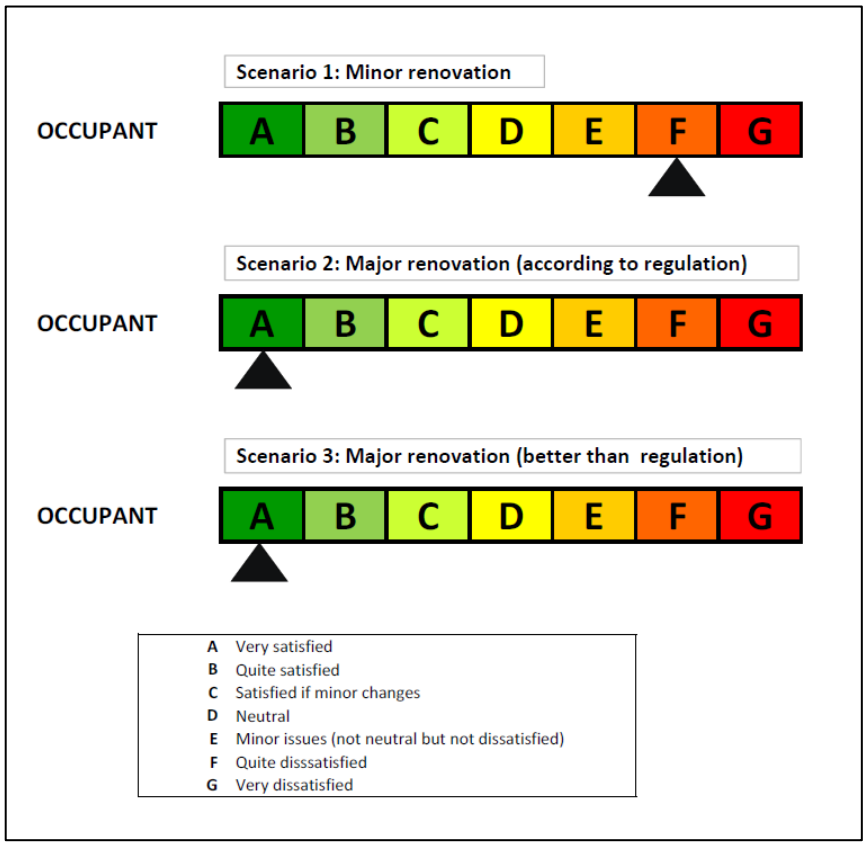


Figure 84: Homeowners' evaluation of the acoustic comfort of the pre-selected scenarios for case study No. 1

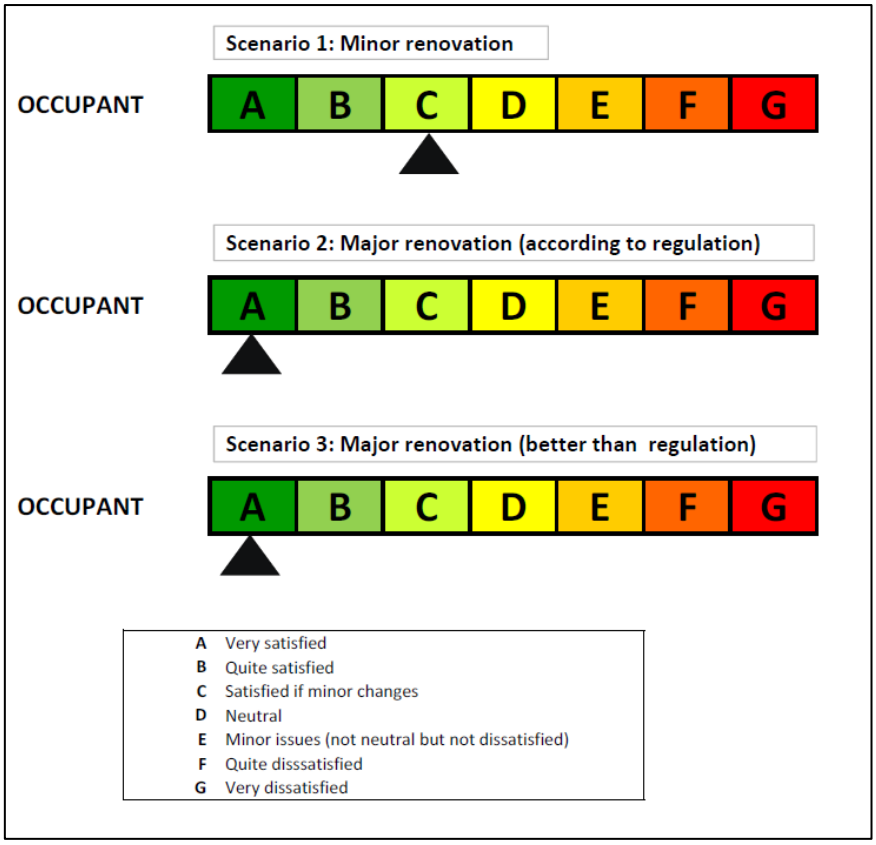


Figure 85: Homeowners' evaluation of the acoustic comfort of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the acoustic comfort, the results are as follow (see Figure 86 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

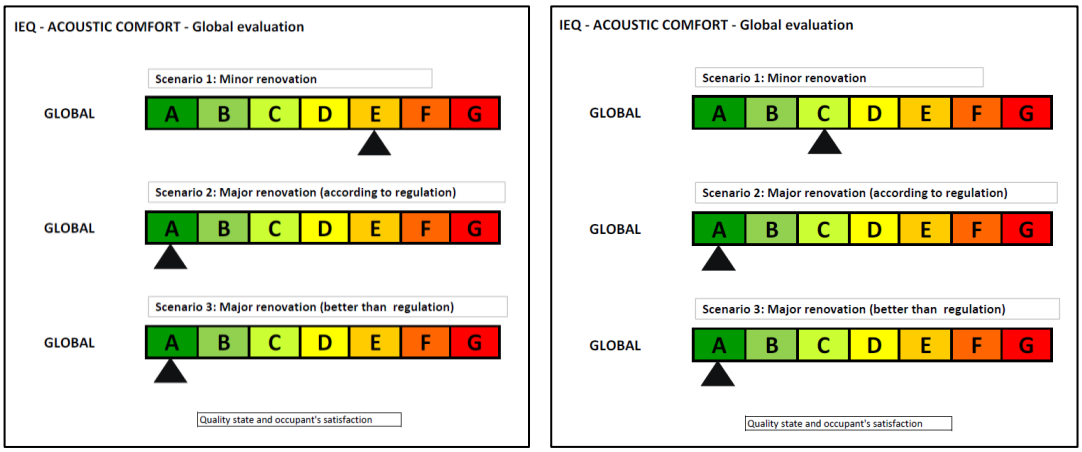


Figure 86: Global evaluation of the acoustic comfort of case studies No. 1 and No. 2

2.6.2.1.5. User control

The evaluation of the user control done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 87 for case study No. 1 and Figure 88 for case study No. 2).

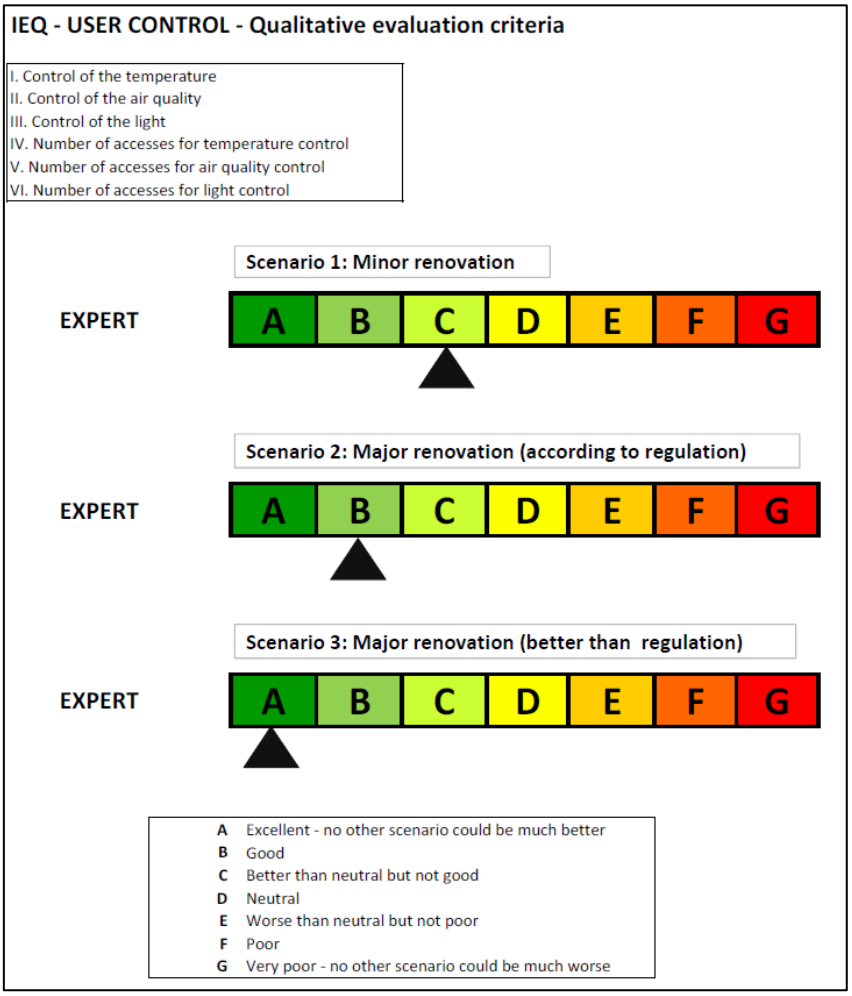


Figure 87: Building expert evaluation of the user control of the pre-selected scenarios for case study No. 1

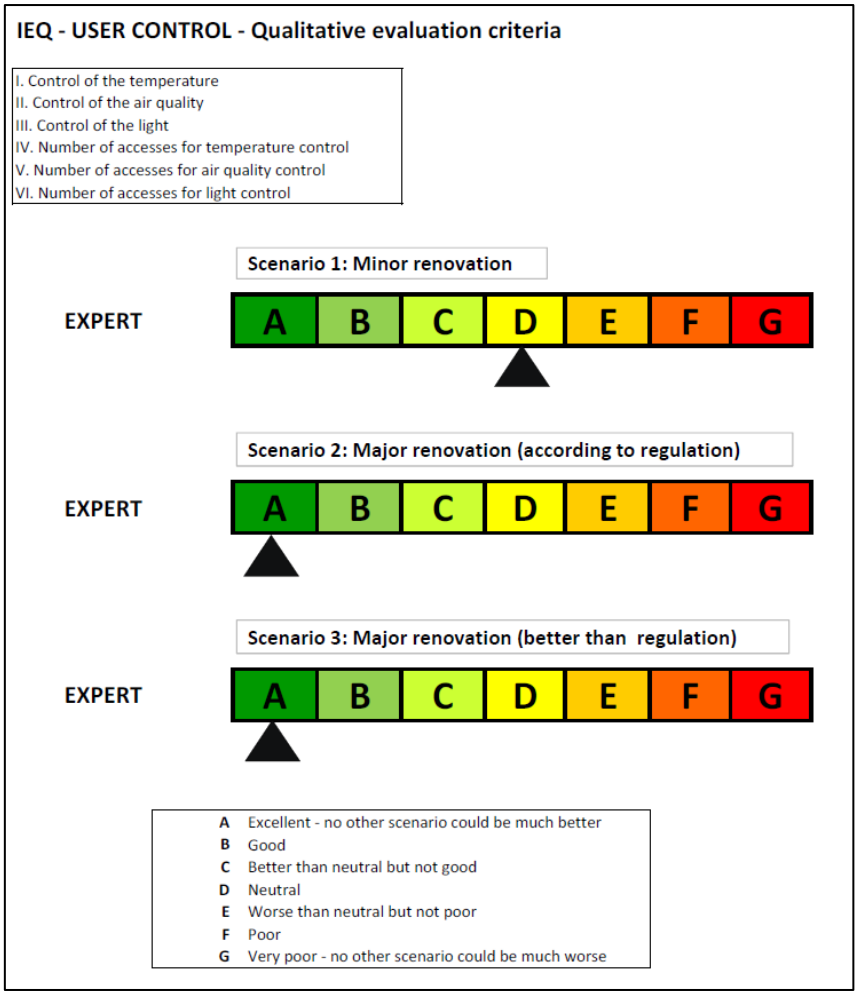


Figure 88: Building expert evaluation of the user control of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the user control they have in their house using the satisfaction scales for the pre-selected scenarios (see Figure 89 for case study No. 1 and Figure 90 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of user control.

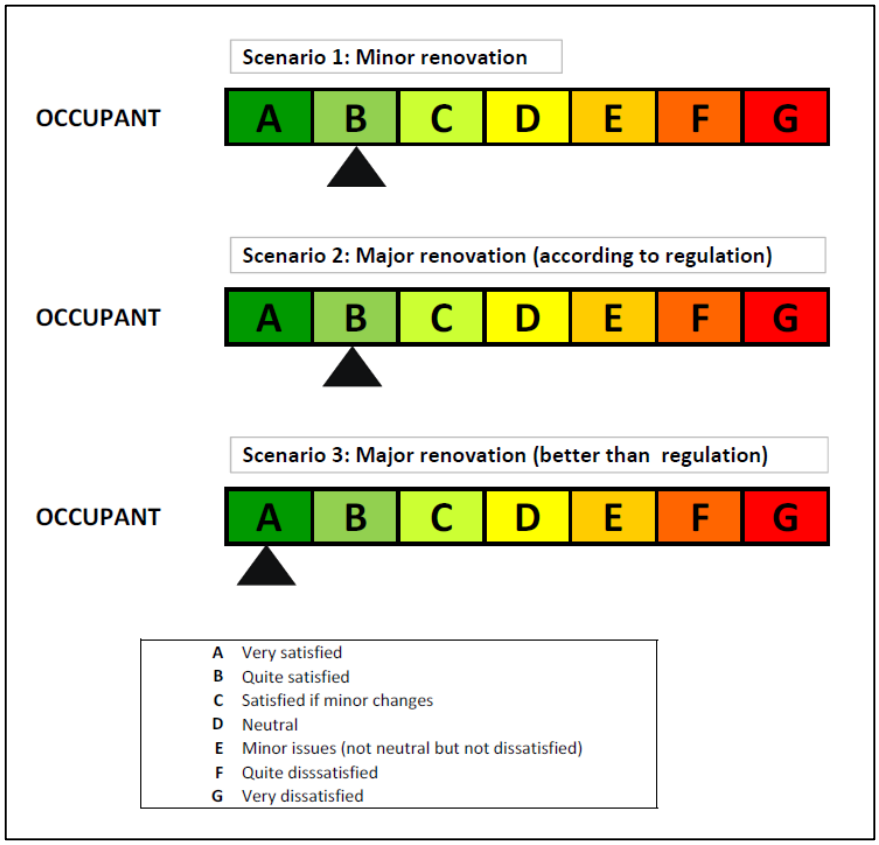


Figure 89: Homeowners' evaluation of the user control of the pre-selected scenarios for case study No. 1

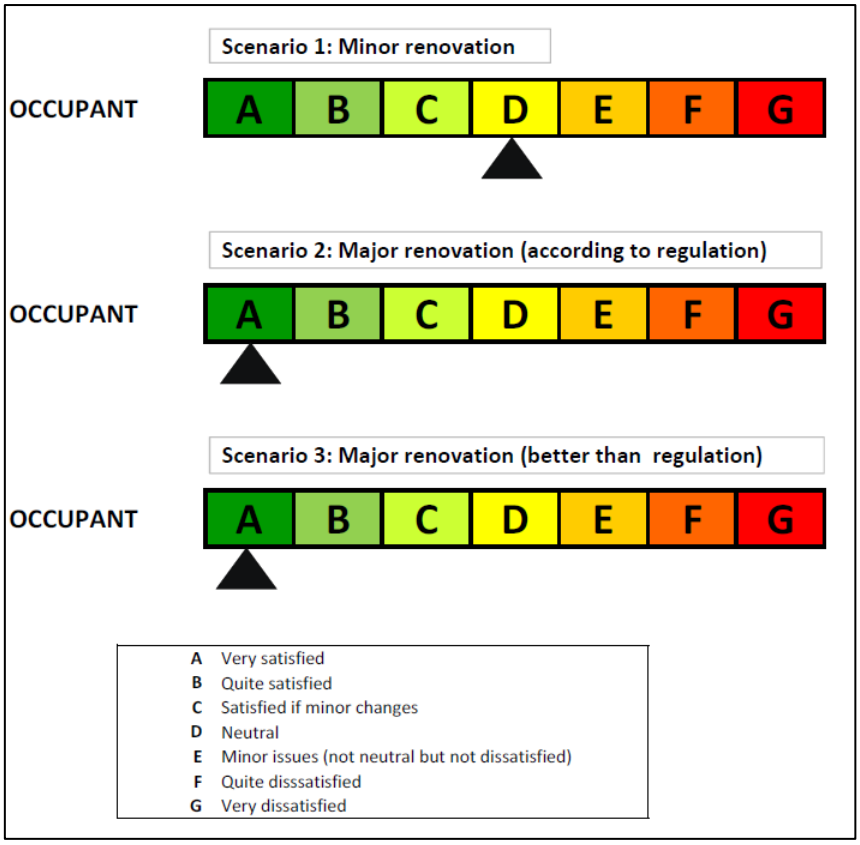


Figure 90: Homeowners' evaluation of the user control of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the user control, the results are as follow (see Figure 91 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

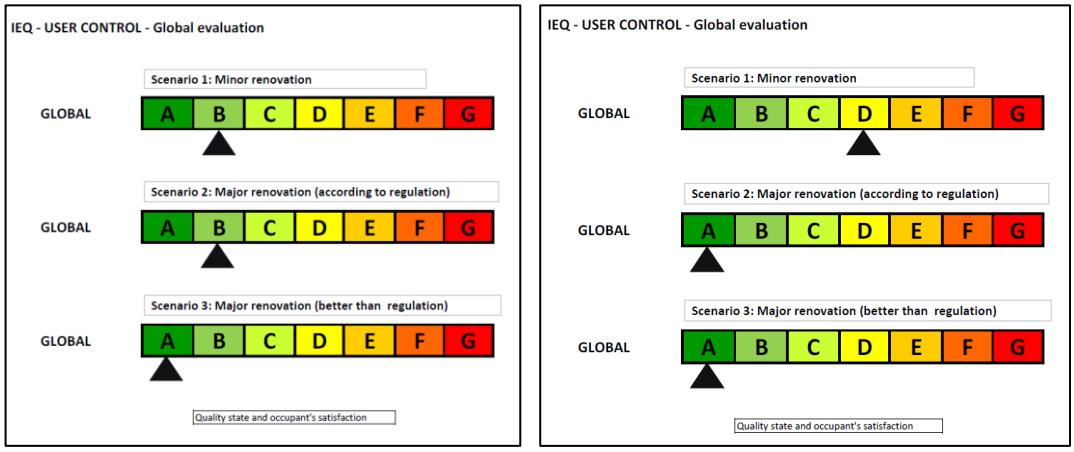


Figure 91: Global evaluation of the user control of case studies No. 1 and No. 2

2.6.2.1.6. Health conditions in the home

The evaluation of the health conditions in the home done by the building expert was presented to the homeowners and justified thanks to the building expert evaluation scale (see Figure 92 for case study No. 1 Figure 93 for case study No. 2).

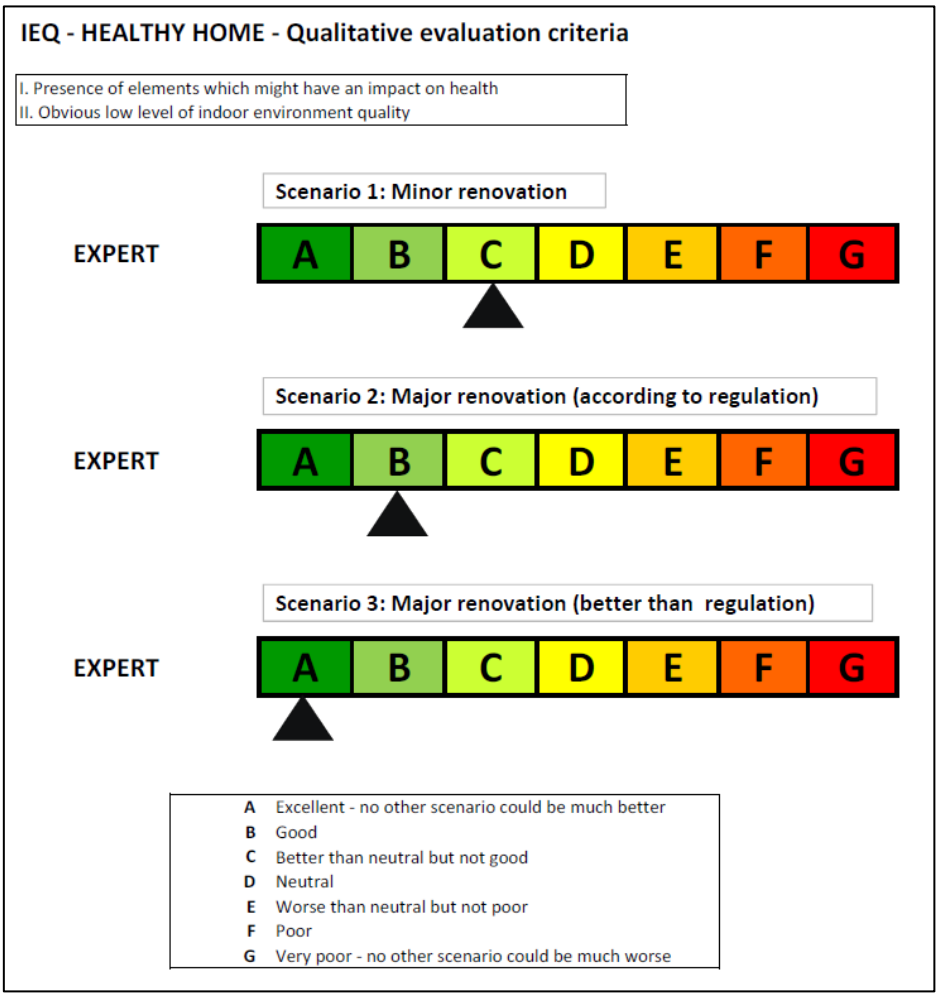


Figure 92: Building expert evaluation of the health conditions of the pre-selected scenarios for case study No. 1

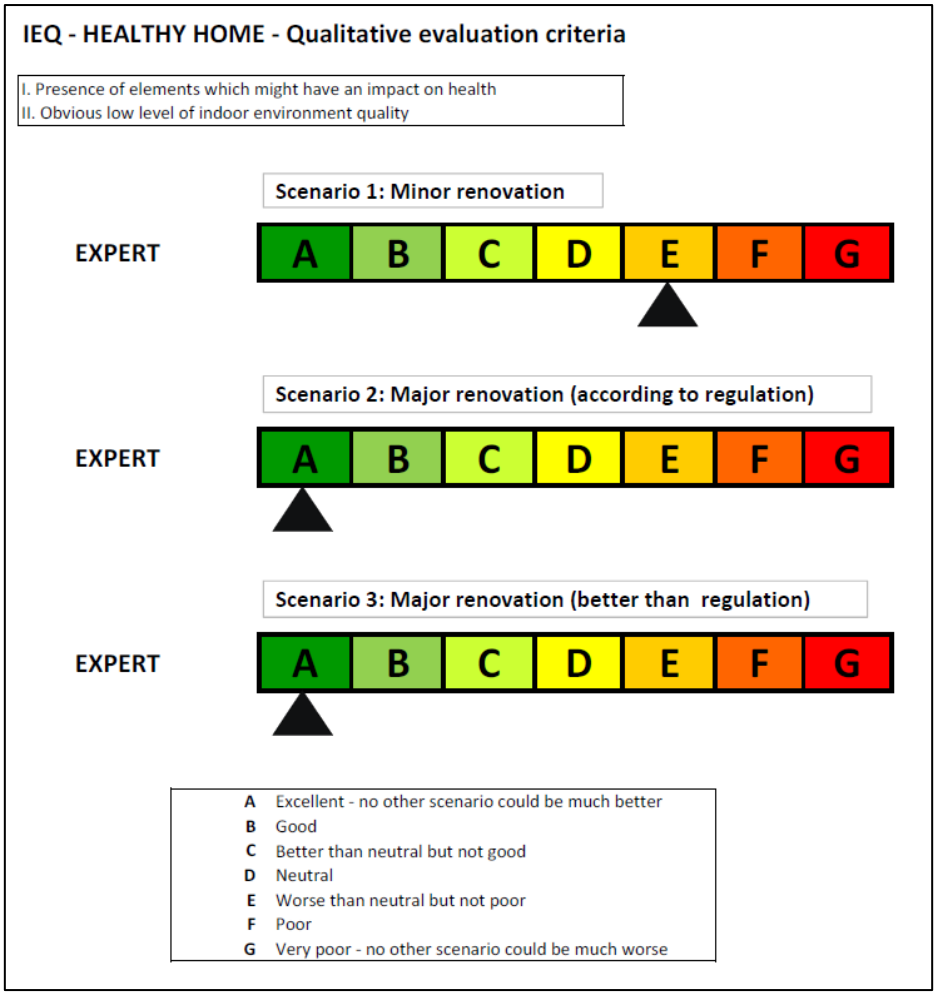


Figure 93: Building expert evaluation of the health conditions of the pre-selected scenarios for case study No. 2

Then, the homeowners were asked to evaluate themselves the health condition in their home the satisfaction scales for the pre-selected scenarios (see Figure 94 for case study No. 1 and Figure 95 for case study No. 2). In order to help them, the building expert presented what plus-value had each scenario and whether their wishes and needs were fulfilled or not. In case of issues with the evaluation of the criteria as a whole, the homeowners were offered to evaluate each theme at the time before giving an evaluation for the whole criteria of healthy home.

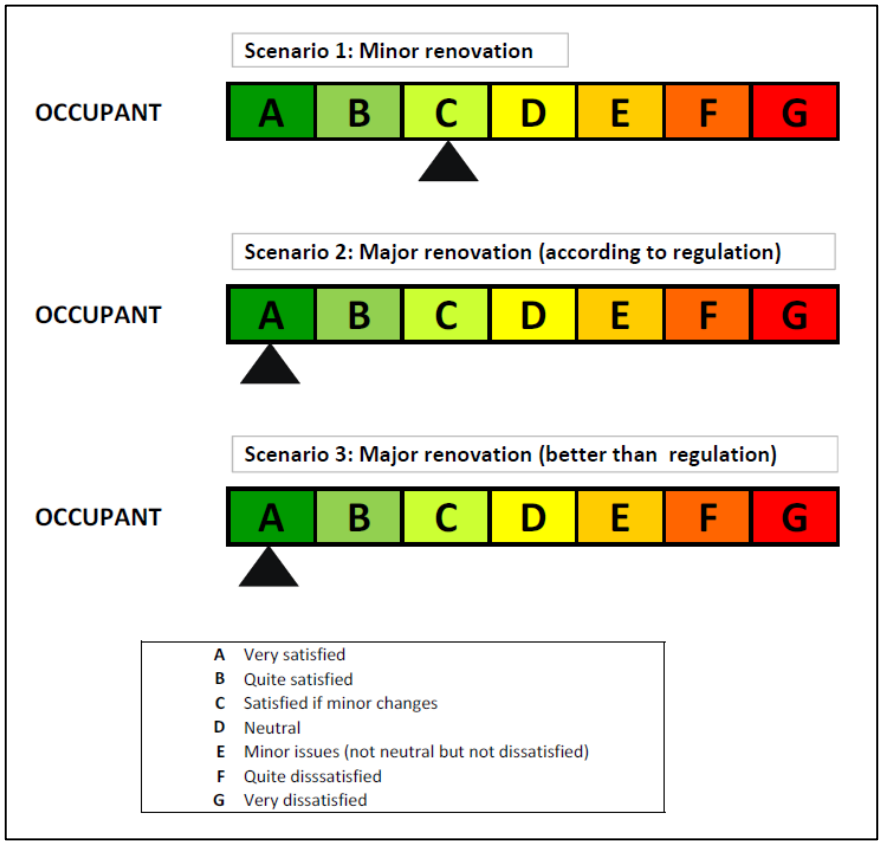


Figure 94: Homeowners' evaluation of the health conditions of the pre-selected scenarios for case study No. 1

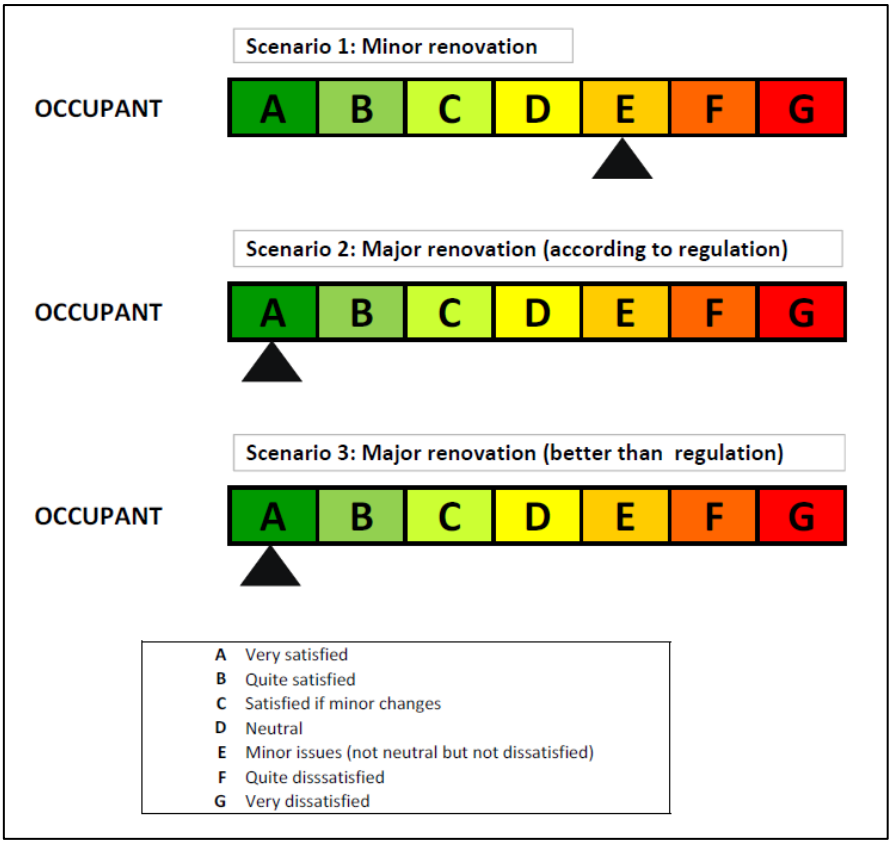


Figure 95: Homeowners' evaluation of the health conditions of the pre-selected scenarios for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation of the health conditions in the home, the results are as follow (see Figure 96 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

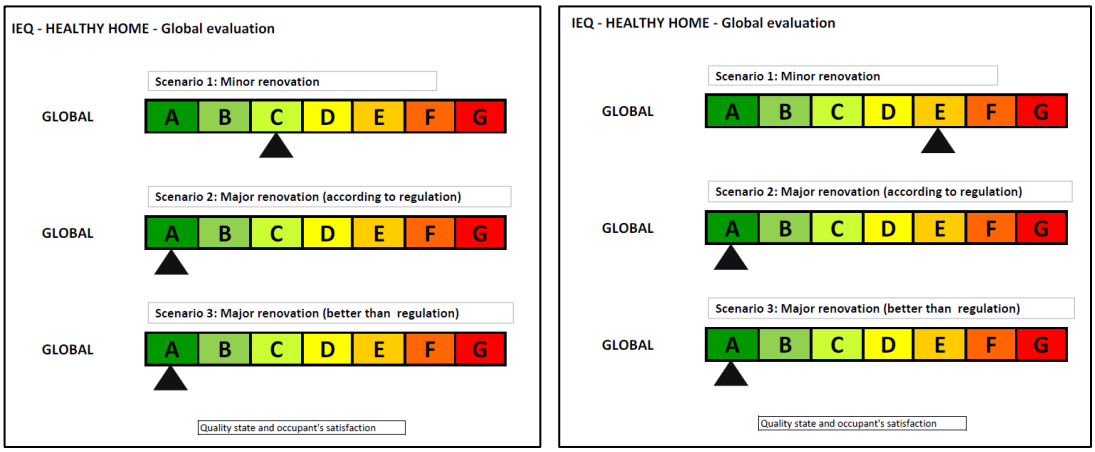


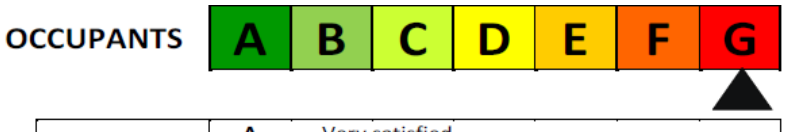
Figure 96: Global evaluation of the health conditions of case studies No. 1 and No. 2

2.6.2.2. Immaterial values

The evaluation of immaterial values has been based on the same themes used for the evaluation of the house in the existing conditions. Visuals were used by the building expert to illustrate the possibilities of improvement and support the homeowners in case of doubts (see Figure 97).

Figure 97: Examples of visual supports used for the evaluation of the immaterial values (Photographers: Mathias Sønderskov Nielsen & Nicolas Galiotto)

As for the evaluation of the house in the existing conditions, the homeowners were not influenced during the evaluation. No building expert evaluation was presented before the homeowners evaluated the immaterial value themes thanks to the same satisfaction scale (see Figure 98).



Favorable	A	Very satisfied
	B	Quite satisfied
Neutral	C	Satisfied if minor changes
	D	Neutral
	E	Minor issues (not neutral but not dissatisfied)
Unfavorable	F	Quite disssatisfied
	G	Very dissatisfied

Figure 98: Evaluation scale used by the homeowners

The results of the evaluation for the pre-selected scenarios are presented in Figure 99 for case study No. 1 and Figure 100 for case study No. 2.

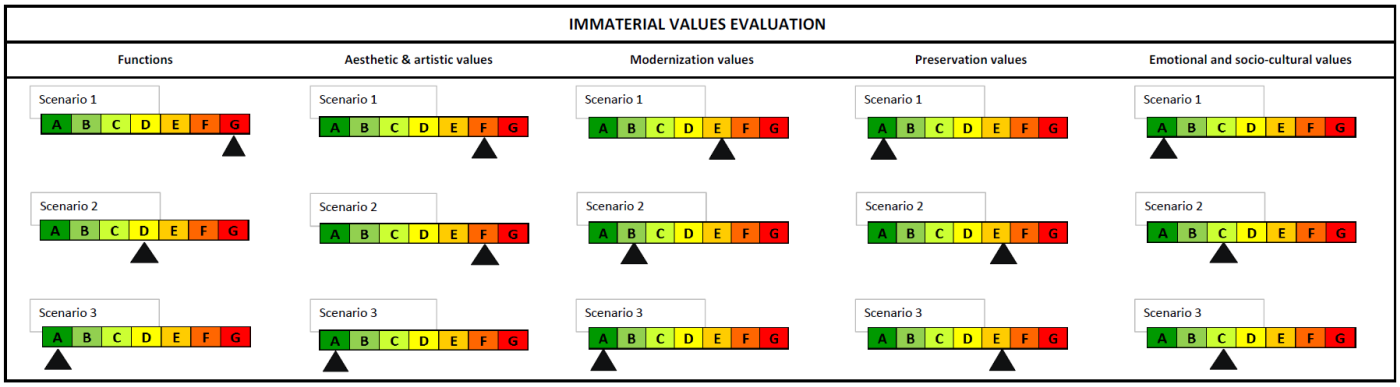


Figure 99: Evaluation of the immaterial values for case study No. 1

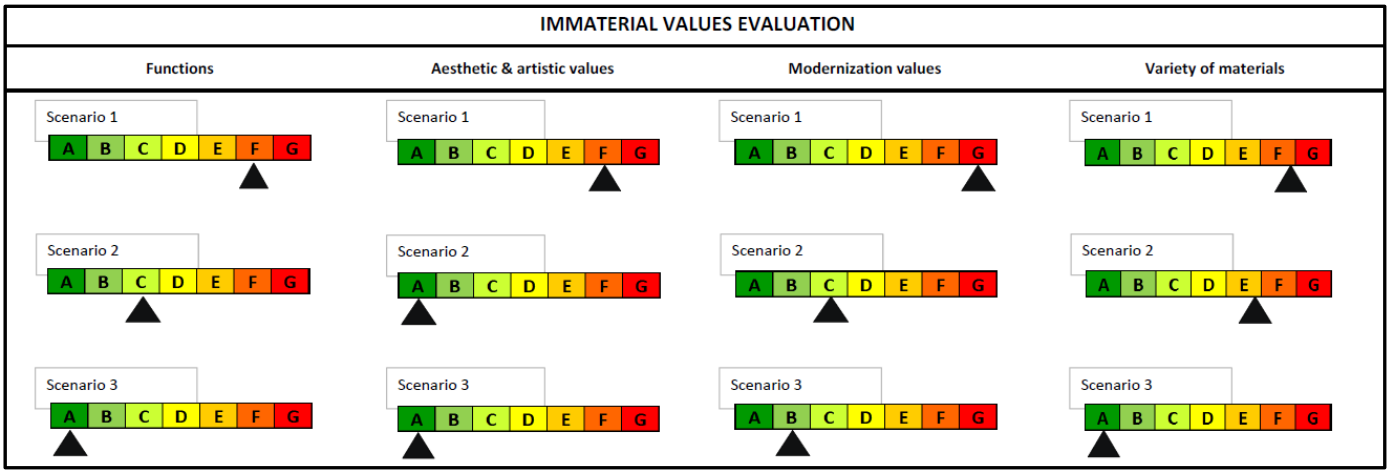


Figure 100: Evaluation of the immaterial values for case study No. 2

2.6.2.3. Economic situation of the homeowners

The evaluation of the economic situation of the homeowners was the last evaluation of the iterative process and was completed for both situations in once; the house in the existing conditions and all pre-selected renovation scenarios. In this approach, the economy main theme includes the investment cost, the energy savings related to the upgrade of the house and the plus-value of the house after renovation. After presentation of the parameters, the potential investment cost was evaluated by the homeowners based on how much they could afford, the plus-value of the house was evaluated by the building expert based on an empirical model and, based on the energy calculations, the savings were estimated and the level of performance was evaluated by both the homeowners and the building expert who then agreed on a result.

Unlike the evaluation of the indoor environment quality and of the immaterial values which are evaluation based on qualitative judgments (or qualitative evaluation), the evaluation of the economic situation of the homeowners is a quantitative evaluation. Alike the evaluation of the energy performance (see paragraph 2.4.2), there is therefore behind every item of the evaluation scale quantities described by an interval of numbers. The quantitative evaluation makes sense if there is a minimum of two thresholds to be defined. The favourable,

neutral/uncertain and unfavourable states are therefore separated by the two thresholds: one threshold indicating the limit of the favourable state while the second threshold indicating the limit of the unfavourable state. In between the two thresholds, the state is neutral or uncertain (see Figure 101).

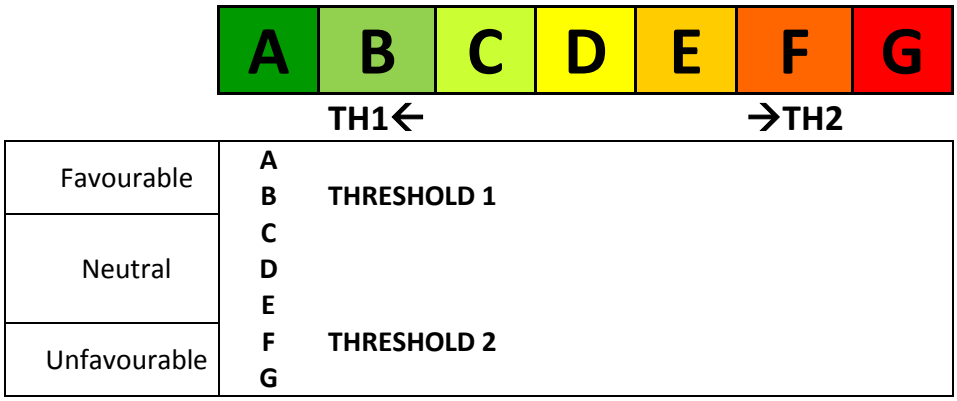


Figure 101: Quantitative evaluation scale with thresholds dividing the states favourableness

However for a house in the existing conditions, no investment is yet made in relation to the renovation. For the scenario of the house in the existing conditions, the yearly energy consumption or the "non-energy savings" and the market value of the house have therefore been taken into account. Indeed, a house not maintained or degraded loses of its market value.

The guiding sheet used by the building expert and the homeowners for the evaluation of the economy / economic situation of the homeowners included the main criteria cited in the previous paragraph (see Figure 102).

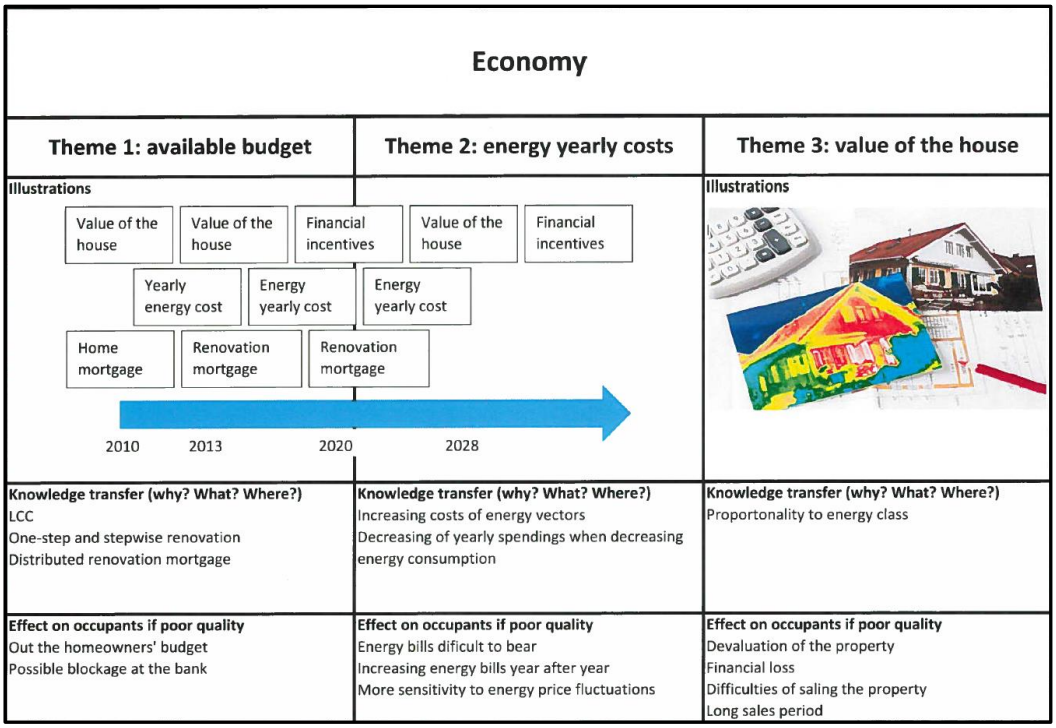


Figure 102: Guiding sheet for the evolution of the economic situation of the homeowners

In the first iteration of the process, the pre-selected alternatives were the following: alternatives 0.0, 1.2, 2.3 and 3.2 for case study No. 1 and alternatives 0.0, 1.2, 2.3 and 3.4 for case study No. 2 (see Table 1).

CASE STUDY No. 1 Scenarios and alternatives	Energy class BR10	Energy yearly savings	Energy yearly costs	House + value due to the improvement of the energy label	Renov. cost Global
Scenario 0 existing conditions	G	kr. 0	kr. 36.961	kr. 0	kr. 0
Scenario 1.1 WR	F	kr. 9.195	kr. 27.765	kr. 83.787	kr. 152.000
Scenario 1.2 WR exhaust	F	kr. 8.339	kr. 28.621	kr. 83.787	kr. 355.000
Scenario 2.1 oil exhaust	D	kr. 14.980	kr. 21.980	kr. 319.637	kr. 1.161.202
Scenario 2.2 ashp exhaust	C	kr. 25.770	kr. 11.191	kr. 419.184	kr. 1.261.202
Scenario 2.3 ashp HRVS	C	kr. 26.771	kr. 10.189	kr. 419.184	kr. 1.306.202
Scenario 3.1 ashp HRVS	B	kr. 28.187	kr. 8.773	kr. 507.871	kr. 1.634.743
Scenario 3.2 ashp HRVS SWH	A	kr. 30.164	kr. 6.797	kr. 507.871	kr. 1.673.000
Scen. 3.3 ashp HRVS + SWH + 2.5KW PV	A (NZEB)	kr. 34.712	kr. 2.248	kr. 507.871	kr. 1.789.000
Scen. 3.4 ashp HRVS + SWH + 4.0KW PV	A (ZEB)	kr. 36.961	kr. 0	kr. 507.871	kr. 1.818.000

CASE STUDY No. 2 Scenarios and alternatives	Energy class BR10	Energy yearly savings	Energy yearly costs	House + value due to the improvement of the energy label	Renov. cost Global
Scenario 0 existing condit.	F	kr. 0	kr. 48.063	kr. 0	kr. 0
Scenario 1.1 Uwin 2,7	E	kr. 7.077	kr. 40.987	kr. 134.693	kr. 193.324
Scenario 1.2 Uwin 1,65	D	kr. 11.478	kr. 36.586	kr. 270.907	kr. 343.324
Scenario 2.1 ashp exhaus	C	kr. 13.821	kr. 34.242	kr. 437.370	kr. 1.483.083
Scenario 2.2 ashp double	B	kr. 19.870	kr. 28.193	kr. 445.971	kr. 1.528.076
Scenario 2.3 gshp	B	kr. 23.211	kr. 24.852	kr. 445.971	kr. 1.609.863
Scenario 3.1 ASHP	A	kr. 31.065	kr. 16.998	kr. 445.971	kr. 1.806.981
Scenario 3.2 GSHP	A	kr. 31.476	kr. 16.588	kr. 445.971	kr. 1.888.768
Scenario 3.3 ASHP + SWH	A	kr. 32.824	kr. 15.240	kr. 445.971	kr. 1.845.238
Scenario 3.4 GSHP + SWH	A	kr. 33.176	kr. 14.888	kr. 445.971	kr. 1.927.025
Scenario 3.5 GSHP + 6SWH + 2 KW PV	A (NZEB)	kr. 42.261	kr. 5.803	kr. 445.971	kr. 2.027.025
Scenario 3.6 GSHP + 6SWH + 3,5 KW PV	A (ZEB)	kr. 48.063	kr. 0	kr. 445.971	kr. 2.062.025

- *Case study No. 1: new windows have an impact on the energy performance of the building but most windows are at the end of their life cycle.*
- *Case study No. 2: new windows have an impact on the energy performance of the building but most windows will reach the end of their life cycle within 10 years.*
- *WR: new windows according to regulation, exhaust: exhaust fans, oil: existing oil boiler, ashp: air source heat pump, HRVS: heat recovery ventilation system, SWH: solar water heater, PV: photovoltaic panels. Renov.: renovation, kr.: Danish kroner, ZEB: zero energy building (excl. appliances), NZEB: nearly zero energy building (excl. appliances).*
- *Hypothesis: cost oil: 12,5 kr./litre, cost electricity: 1,25 kr./Kwh, inflation is not taken into account, energy prices are not increasing in time (safe side).*

Table 1: Economy evaluation results for each alternative of case studies No. 1 & No. 2

2.6.2.3.1. Evaluation of the level of performance in terms of energy savings / costs

The effects or impacts on the occupants in case of high energy bills were presented to the homeowners and they were directly asked whether they had experienced those effects and if they were somewhat able to quantify it. From there, the quantitative evaluation (calculations, simulations and comparison with bills from previous years) of the yearly energy costs done by

the building expert was presented to the homeowners beside a proposition of thresholds to divide the favourable from the unfavourable (see Figure 103 for case study No. 1 and Figure 104 for case study No. 2).

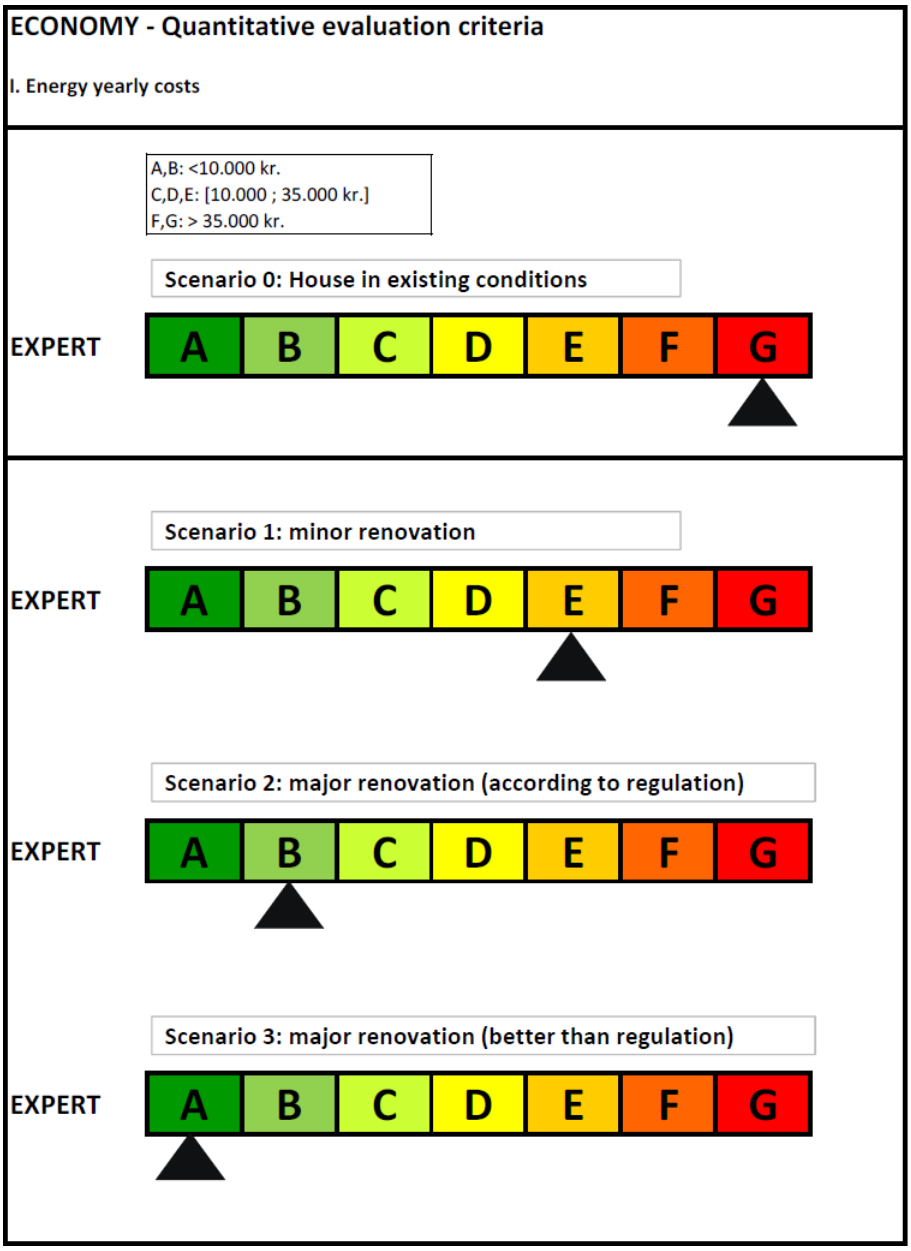


Figure 103: Building expert evaluation of the energy yearly costs for the case study No. 1 in the existing conditions of the house and for all pre-selected renovation scenarios

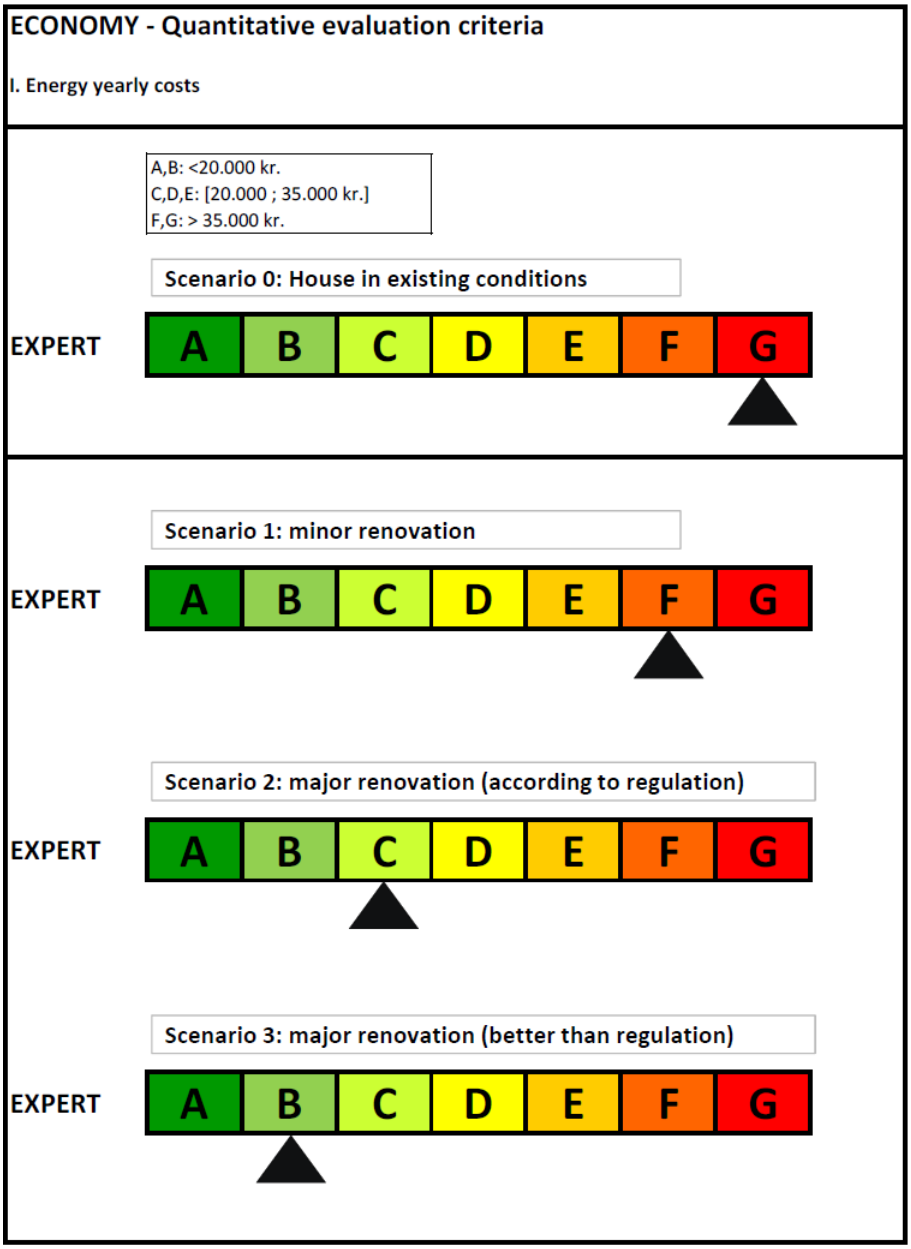


Figure 104: Building expert evaluation of the energy yearly costs for the case study No. 2 in the existing conditions of the house and for all pre-selected renovation scenarios

In the same approach that for the evaluation of the previous criteria, the homeowners were asked to evaluate themselves the yearly energy costs in the existing conditions and for all pre-selected scenarios using the satisfaction scales (see Figure 105 for case study No. 1 and Figure 106 for case study No. 2). The homeowner of case study No. 1 agreed with the thresholds suggested by the building expert while the homeowners of case study No. 2 did not agree with the building expert suggestions. The threshold for a favourable situation had to be for them lower yearly costs that what they had in their previous house and this no matter if the newly purchased house is bigger. They therefore suggested a threshold of 15.000 kr. yearly in comparison to the 20.000 kr. that the building expert had suggested.

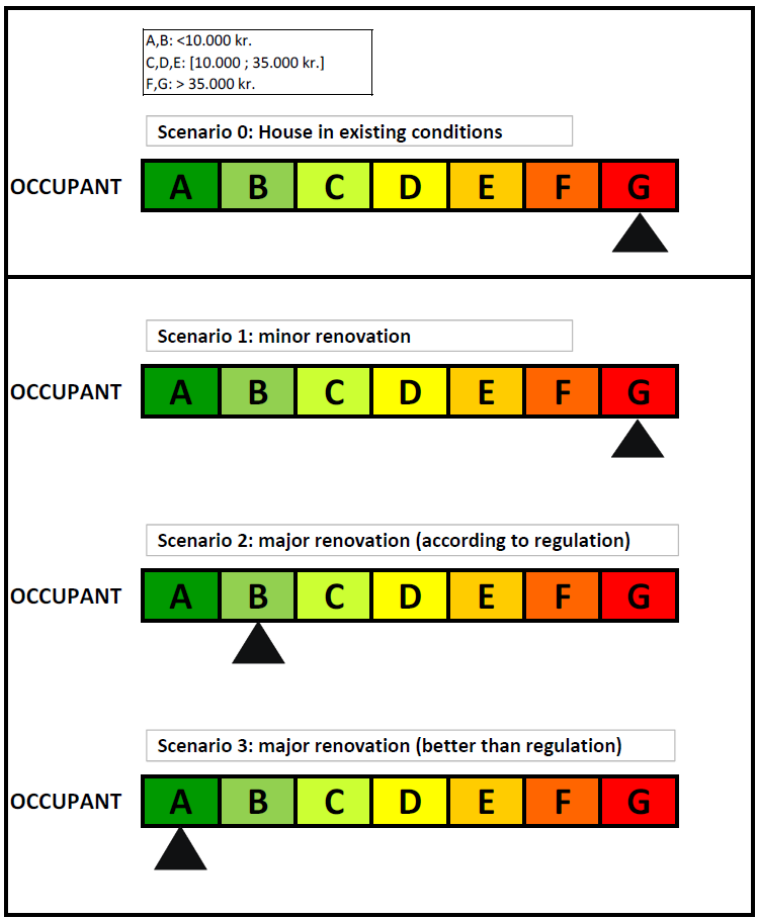


Figure 105: Yearly energy costs evaluation according to the homeowner for case study No. 1

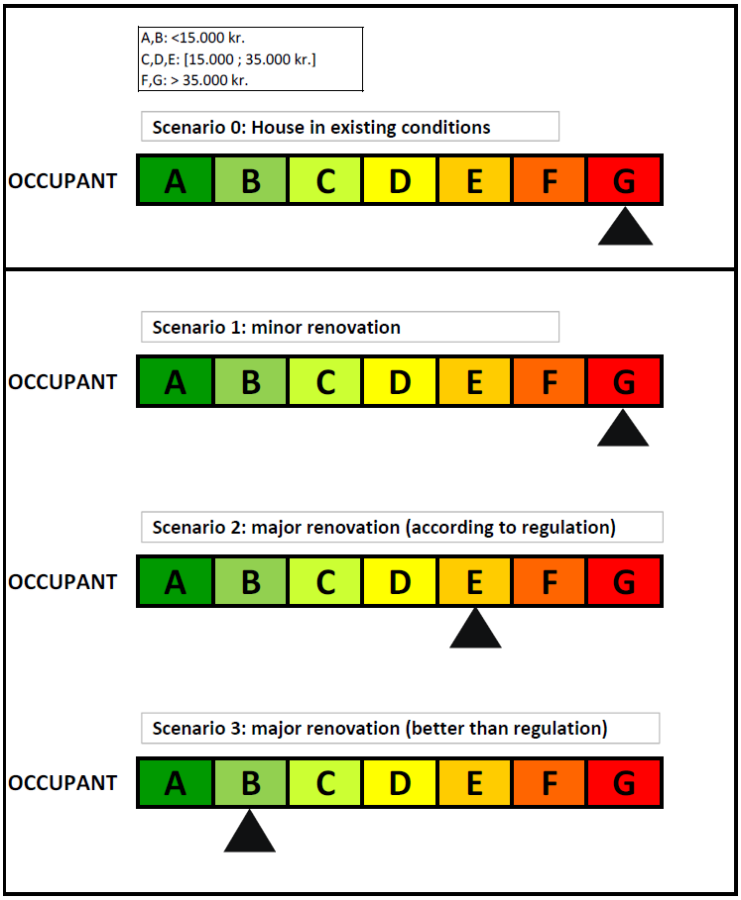


Figure 106: Yearly energy costs evaluation according to the homeowner for case study No. 2

Once, the homeowners done with their evaluation in terms of satisfaction, both the building expert and the homeowners agreed on a global evaluation for the yearly energy costs (see Figure 107 on the left hand side for case study No. 1 and on the right hand side for case study No. 2).

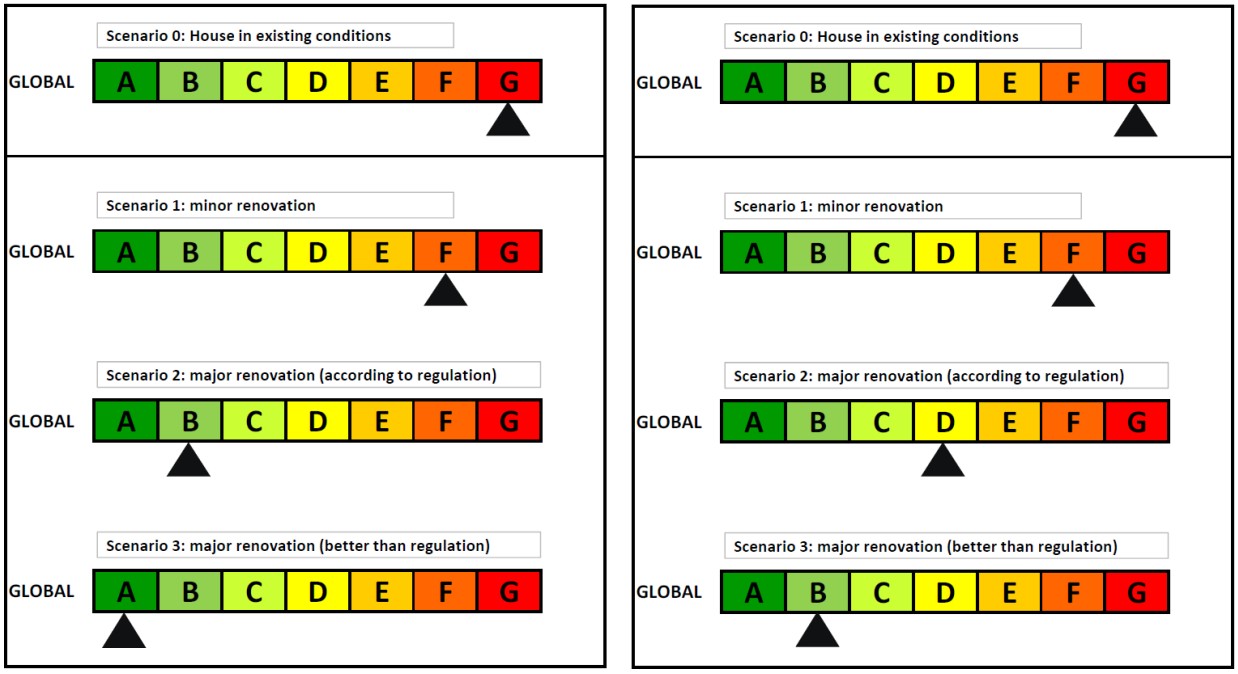


Figure 107: Global evaluation of the energy yearly costs for case studies No. 1 and No. 2

2.6.2.3.2. Evaluation of the renovation total cost vs. available budget

The evaluation of the renovation total cost compared to the available budget was evaluated by the homeowners alone. No building expert evaluation was made prior to the homeowners' evaluation. The estimated total renovation costs of the three scenarios including variations with the alternatives within each scenario were presented to the homeowners. They were then asked to define the two thresholds for two situations: in the case of a one-step renovation in which the investment should be made in once and the case of a stepwise renovation in which the investment could be spread out in time (e.g. with one year of interval between the renovation steps or more). The first threshold would define an investment (one-step or stepwise) which was bearable for the homeowners considering the qualities they were getting in their new renovated home. While the other threshold would define a limit over which they knew it was critical (again for one-step and stepwise renovations). In the case study No. 1, the homeowner had no doubt about wanting to renovate in a one-step renovation process in order to benefit directly of all qualities of the newly renovated home. The thresholds were therefore of the same order for both types of processes, one-step and stepwise renovation (see Figure 108).

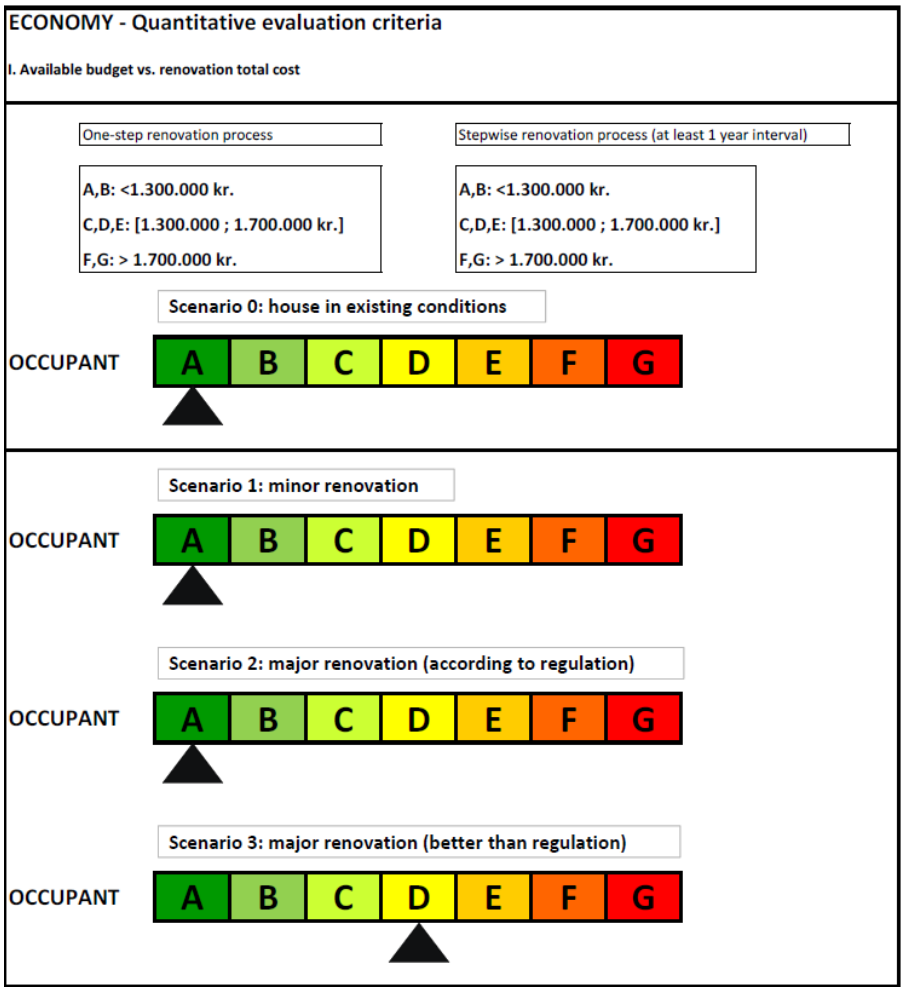


Figure 108: Available budget vs. total renovation cost for case study No. 1

In the case of case study No. 2, it was different. The budget accorded to a one-step renovation process was limiting the renovation depth. The use of a stepwise renovation process was therefore in this case opening to the possibility of a major renovation. The thresholds were therefore different in case of stepwise renovation process (see Figure 109).

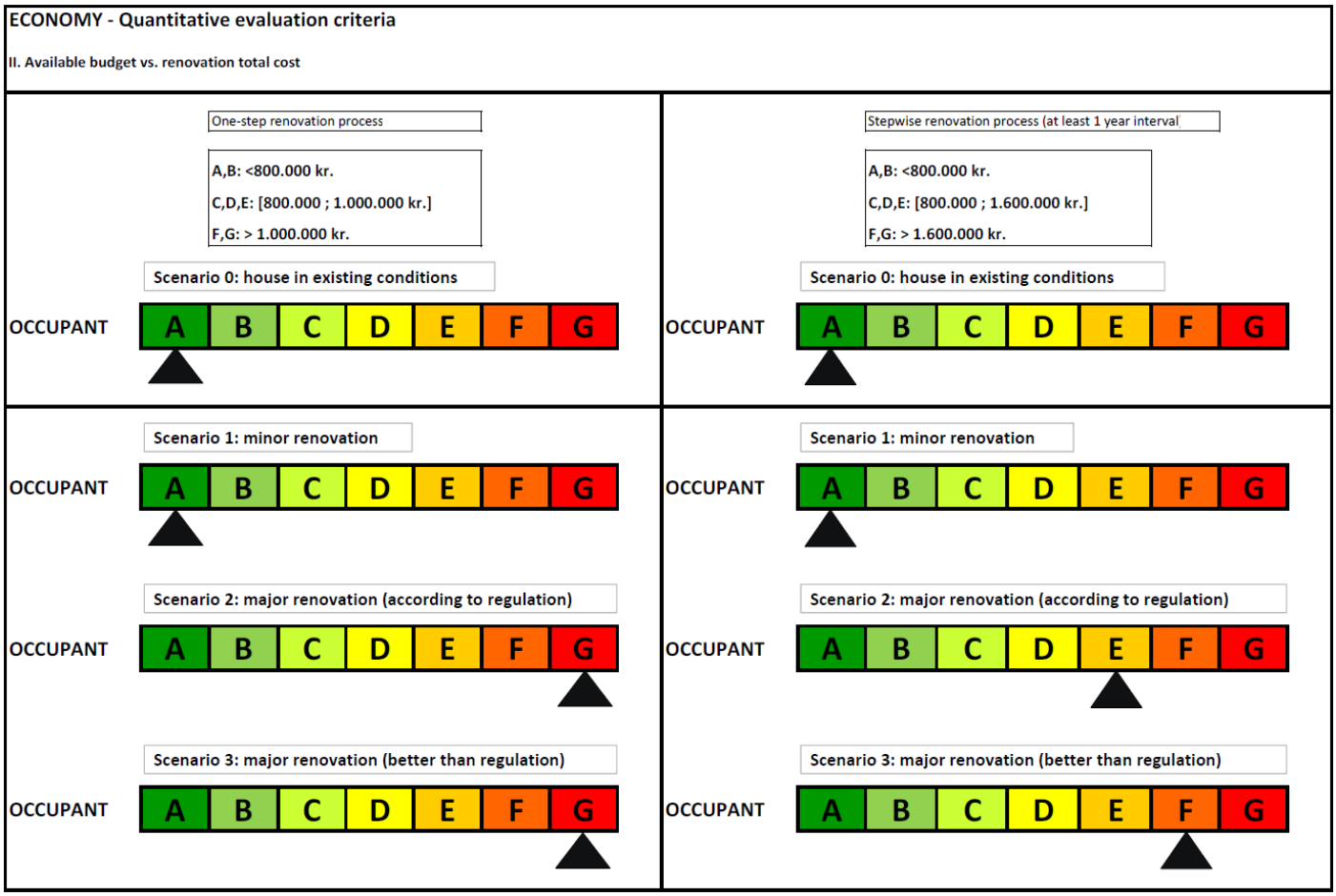


Figure 109: Available budget vs. total renovation cost for case study No. 2 for a one-step renovation process and a stepwise renovation process

2.6.2.3.3. Evaluation of the level of performance in terms of market plus-value of the house

The effects or impacts on the occupants in case of non-maintenance or upgrade of the house and therefore loss of market value of the house were presented to the homeowners. From there, the quantitative evaluation (based on empirical model) of the plus-value or loss of value done by the building expert was presented to the homeowners. In the case of this criterion, the homeowners were proposed again to define themselves the thresholds to separate the favourable plus-value of the house to the unfavourable plus-value or even worse loss of market value. To do so, all the scenarios with different plus-values or loss of value were presented in a way that homeowners could find their thresholds within an interval of quantitative values (see Table 1). Two points were bothering the homeowners: firstly, they were expecting the house plus-values due to the improvement of the energy label to be globally higher. Secondly, they were bothered that a renovated house just complying with the regulation of new residential buildings (A 2010) had the same plus-value that a nearly zero energy or zero energy renovated house. The building expert therefore had to explain them that: firstly the empirical model used was given a plus-value of the house uniquely related to an improvement of the energy label but that other improvements could also bring some plus-value. It was therefore more a safety

value. Secondly that the model could not differentiate house of energy class B, A 2010, A 2015 or A 2020 (see EPBD according to Denmark) but that the plus-values related to these types of renovated houses were likely to be different even they could not be evaluated more accurately. Because of the high uncertainties, the evaluation of the house plus-value due to the improvement of the energy label had to be taken as indicative more than decisive. The results are similar for both case studies (see Figure 110).

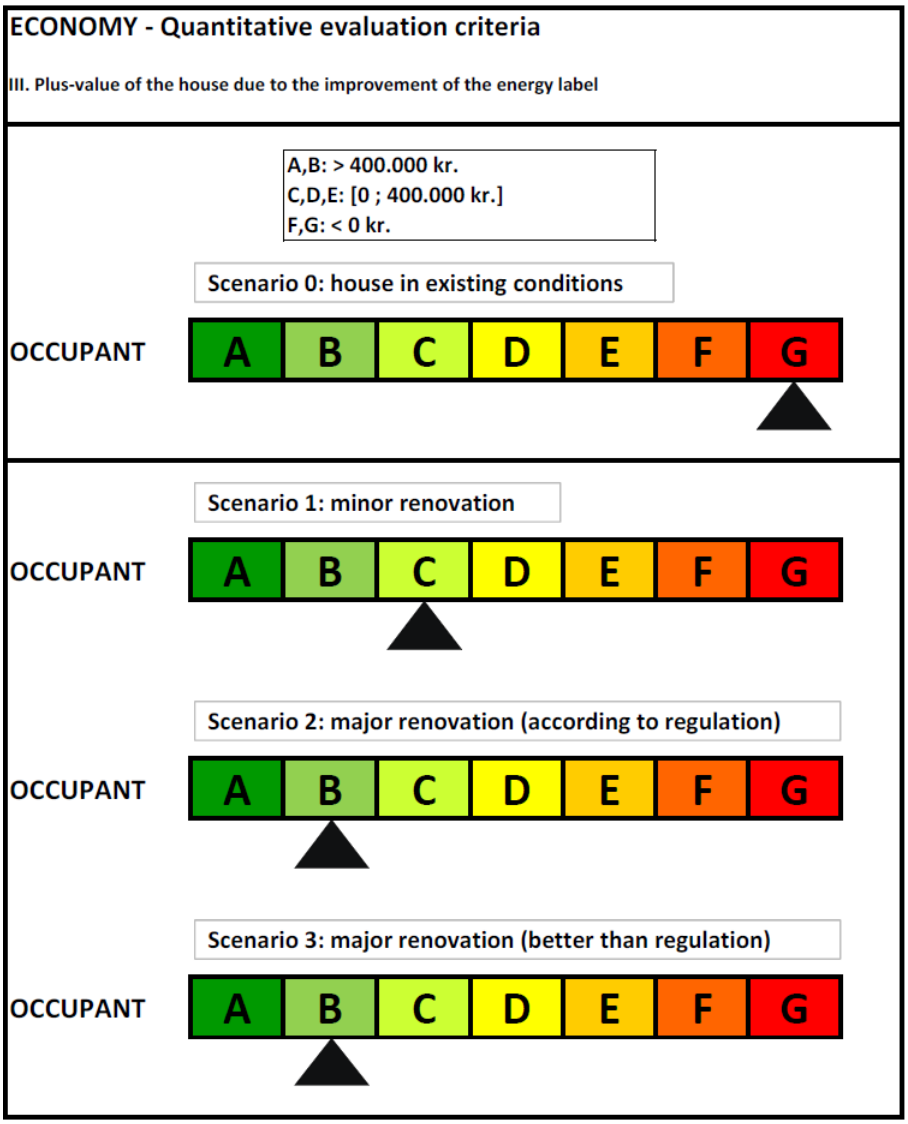


Figure 110: Evaluation of the house plus-value due to the improvement of the energy label according to the homeowners for all scenarios for both case study No. 1 and No. 2

2.7. Synthesis and presentation of the results

2.7.1. Discussion of results

Technical aspects

While the house in the existing conditions is in a poor to critical state of degradation (wear-out) and obsolescence and in a poor level of energy performance (energy class G for case study No. 1 and energy class G for case study No. 2), the scenario 1 would bring the building to a more acceptable (but still unfavourable) states of degradation and technical obsolescence as well as to a better level of energy performance (energy class F for case study No. 1 and energy class E or D for case study No. 2). Scenarios 2 and 3 (including all the options) would bring most building equipment and materials to good states of degradation and technical obsolescence and to acceptable to excellent levels of energy performance (classes D to A1 for case study No. 1 and energy classes C to A for case study No. 2).

Indoor Environment Quality

According to the homeowners and to the building expert, the houses in the existing conditions have an unsatisfying state of comfort and health (indoor environment quality) for both case studies No. 1 and No. 2. In both case studies, scenario 1 would not bring the buildings to a state, good enough, to be satisfying the occupants. Scenario 2 (including all the alternatives) would bring the building to a good state of comfort and health while scenario 3 (including all the alternatives) would bring the building to an excellent state of comfort and health.

Immaterial values

According to the homeowner of case study No. 1, the house in the existing conditions has an unsatisfying state of immaterial values. Even if the outdoor look of the house reassures psychologically the homeowner, the functionality inside and outside the home is not satisfying. The aesthetic as well as the artistic values could be improved and, social life qualities and more specifically possible interaction with visitors could be enhanced. According to the homeowners of case study No. 2, the house in the existing conditions has an unsatisfying state of immaterial values. The outdoor look of the house is not at all in phase with the image that the homeowners want to emit, the functionality inside and outside the home is not satisfying either. The aesthetic as well as the artistic values could be improved and, social life qualities could be enhanced. These homeowners would also like more diversity of materials.

In case study No. 1, scenario 1 would keep the reassuring outdoor look but won't bring a global satisfying state of immaterial values to the occupant. In case study No. 2, scenario 1 would not modernize the outdoor look or any artistic value, neither the functionality indoor or outdoor. It won't therefore bring a global satisfying state of immaterial values for the occupants.

In case study No. 1, scenario 2 (including all the alternatives) would improve grandly the artistic values of the house keeping that reassuring architectural expression. However functionality and social life qualities and more specifically possible interaction with visitors should still be improved to reach a state where the homeowner feels entirely satisfied. In case study No. 2, scenario 2 (including all the alternatives) would improve grandly the artistic values of the house giving a much more modern expression. However functionality and social life qualities as well as diversity and quality of materials should still be improved to reach a state where the homeowner feels entirely satisfied.

Scenario 3 (including all the alternatives) would give entire satisfaction to the homeowners of both case studies in terms of immaterial values.

Economy

While the houses in the existing conditions will lead the homeowners toward increasing energy spending, that scenario would need almost no investment. This would however lead the houses to lose in value due to the exacerbating degradation state of the buildings. Scenario 1 would bring limited (theoretical) yearly energy savings (+/- 9000 kr. for case study No. 1 and +/- 7000 to 11.000 kr. for case study No. 2) with a limited initial investment. This scenario would bring a small energy-related plus-value to the building (84.000 kr. for case study No. 1 and 135.000 to 270.000 kr. for case study No. 2) compensating easily the investment connected to the energy-related measures.

Scenario 2 would bring more important (theoretical) yearly energy savings (from 25.000 to 29.000 kr. for case study No. 1 and from 14.000 to 23.000 kr. for case study No. 2) with a more important initial investment. This scenario would also bring a more important energy-related plus-value to the building (420.000 kr. for case study No. 1 and 437.000 to 446.000 kr. for case study No. 2) still compensating the investment connected to the energy-related measures.

Scenario 3 would bring excellent (theoretical) yearly energy savings (from 28.000 to 37.000 kr. for case study No. 1 and from 31.000 to 48.000 kr. for case study No. 2) with a more important initial investment. This scenario would bring an even important energy-related plus-value to the building (510.000 kr. for case study No. 1 and 446.000 kr. for case study No. 2) compensating the investment connected to the energy-related measures and almost compensating for the other scenarios 3 (3.3 to 3.6) of case study No. 2.

2.7.2. Synthesis and aggregation

2.7.2.1. Introduction

In order to be able to make a final decision, it is sensible to have a synthetic result of the analysis of the diverse scenarios. We are therefore synthesizing the final results hereafter using the method Hermione (Flourentzou et al., 2003). The evaluations of the criteria are synthesized into the corresponding macro-criteria evaluations. These macro-criteria evaluations were then aggregated into a global evaluation. It is important to be aware that the information embedded into this global evaluation becomes quite diluted and it is therefore advised to present the results of the macro-criteria evaluations beside the global evaluation result so the decision makers can have a more truthful look at the results.

Behind each colour is hidden a rich content of information which was progressively transmitted to the homeowners or exchanged during the evaluations. All this information has not been transcribed in this report (discussions, explanations, visuals, etc.). The green colour means that the specific criterion or the global evaluation is favourable; the yellow colour means that it is uncertain i.e. neither favourable nor unfavourable, finally the red colour means it is unfavourable (see Figure 111).

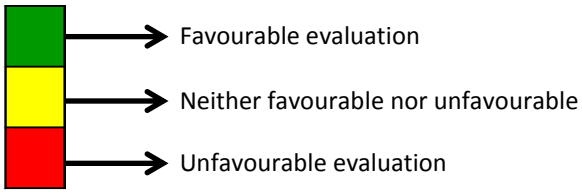


Figure 111: Illustration of the states of favourableness

The synthesis and aggregation rules are of two types:

1. The homeowners were able to aggregate in their minds and to give directly an aggregated result (e.g. all criteria evaluations were unfavourable e.g. red "G" evaluations and therefore the aggregated result was logically unfavourable (i.e. red colour)).
2. The homeowners had a bit of difficulty to aggregate and Hermione rules were then applied. These rules are based on the concept of conditional majority. An absolute majority of favourable evaluations without the presence of unfavourable evaluation gives an aggregated favourable result. Whereas, more than a third of unfavourable evaluations gives an aggregated unfavourable result unless in the meanwhile there is more than a third of favourable evaluations, in that case, there needs to be more than an absolute majority of unfavourable evaluations (see Table 2).

Green (G)		Favourable	$G \geq 50\%$ and $R = 0\%$
Yellow (Y)		Uncertain	$0 < R \leq 33\%$ and $G \geq 50\%$) OR ($G < 50\%$ and $R = 0$) ($33\% < R \leq 50\%$ and $G \geq 50\%$)
Red (R)		Unfavourable	($R > 33\%$ and $G < 50\%$) OR ($R > 50\%$ and $G \geq 33\%$)

Table 2: Hermione aggregation rules

2.7.2.2. Synthesis of the criteria evaluations into a macro-criteria evaluation

2.7.2.2.1. Dilution of the quality of the information

Any user of a multi-criteria decision making method must be aware than more the evaluations are synthesized more the quality of the results is diluted. When dealing with non-expert decision makers, it is therefore obvious that this dilution of the depth of the information needs to be highlighted during the presentation of the results so the decision makers are not too biased when making their decision. We have lightly adapted Hermione method scale so the non-expert decision makers can start to evaluate with a scale which they are familiar (e.g. the European energy label for a washing machine) and which they are kept aware that the last result is a diluted information not as meaningful that the detailed or specific evaluation (of the sub-criteria). This phenomenon is illustrated in Figure 112.

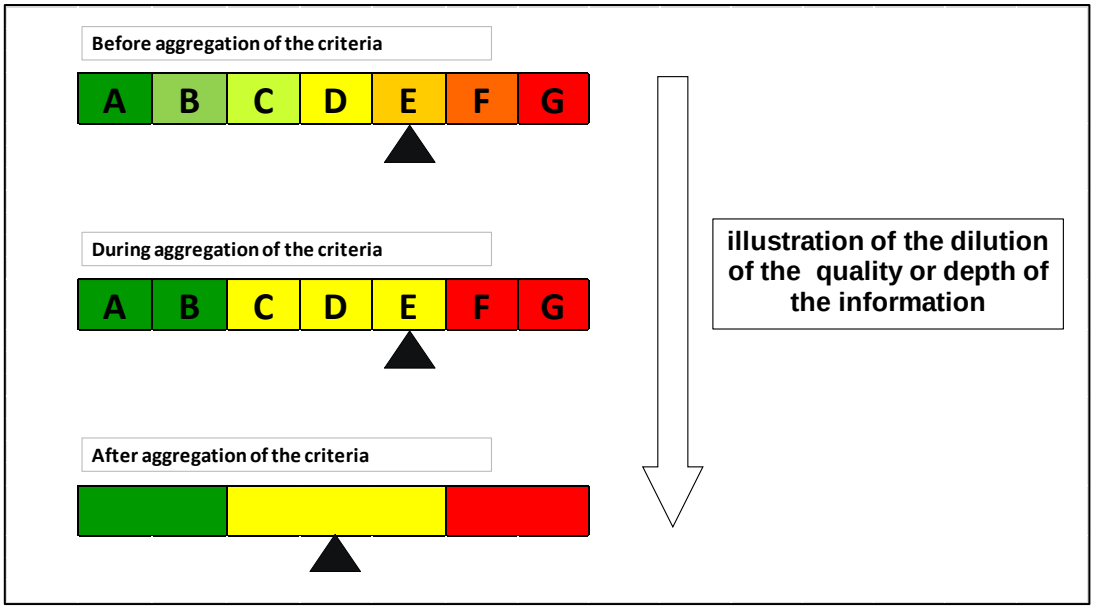


Figure 112: Illustration of the dilution of the quality or depth of the information

2.7.2.2.2. Synthesis of the criteria evaluations into a macro-criteria evaluation

Because the synthesis of the sub-criteria into criteria has been done mostly in the homeowners minds without these intermediary results, we are presenting here after directly the synthesis of the criteria into macro-criteria.

2.7.2.2.2.1. Synthesis of the criteria dealing with the technical aspects

The synthesis of the evaluations of the criteria dealing with the technical aspects has been done by the building expert using Hermione aggregation rules only. The results for both the house in the existing conditions and the preselected renovation scenarios have been presented as follow (see Figure 113 for case study No. 1 and Figure 114 for case study No. 2).

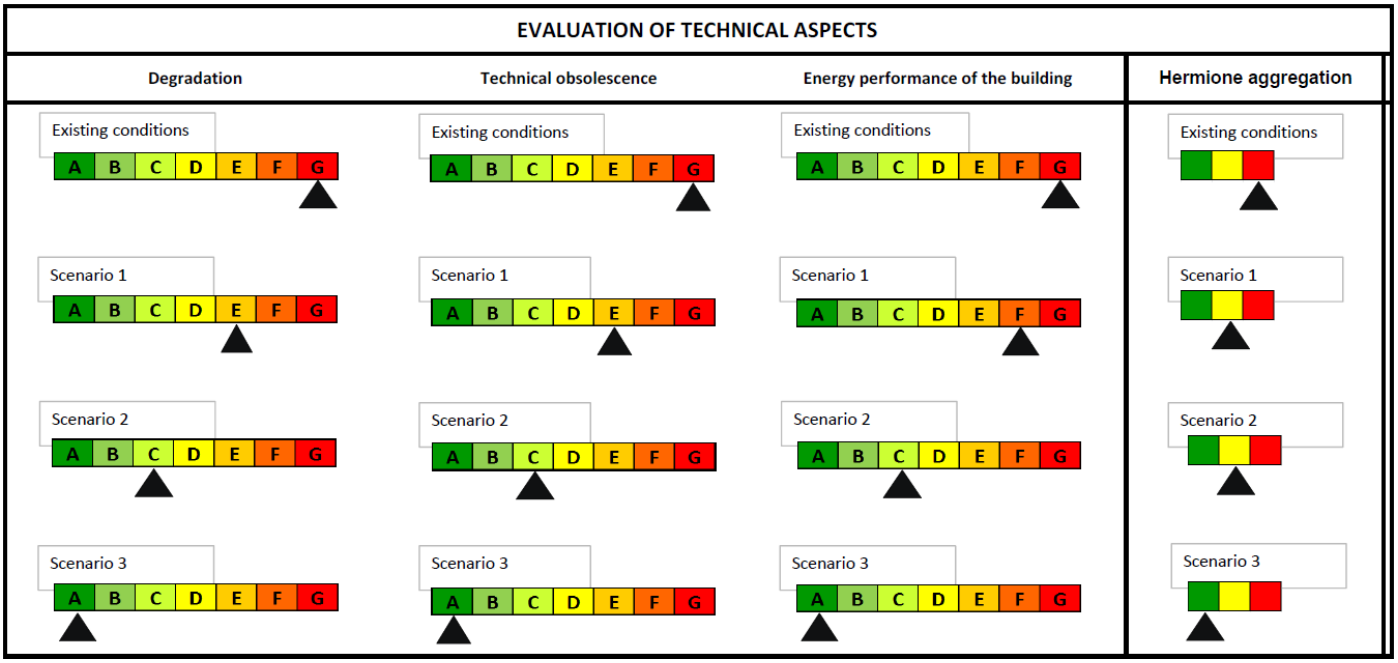


Figure 113: Evaluation and synthesized results for the technical aspects for case study No. 1

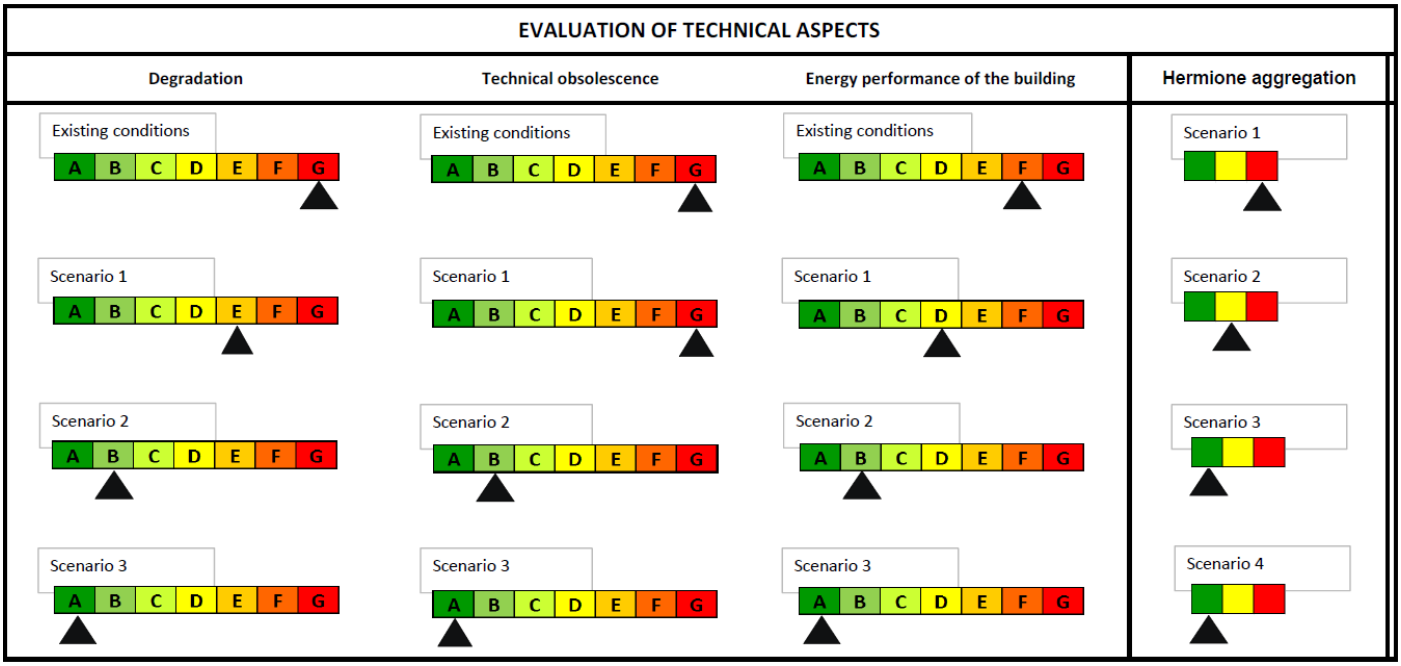


Figure 114: Evaluation and synthesized results for the technical aspects for case study No. 2

2.7.2.2.2. Synthesis of the criteria dealing with the indoor environment quality

The synthesis of the evaluations of the criteria dealing with the indoor environment quality has been done the homeowners directly in their minds or using Hermione aggregation rules. The results for both the house in the existing conditions and the preselected renovation scenarios have been presented as follow (see Figure 115 for case study No. 1 and Figure 116 for case study No. 2).

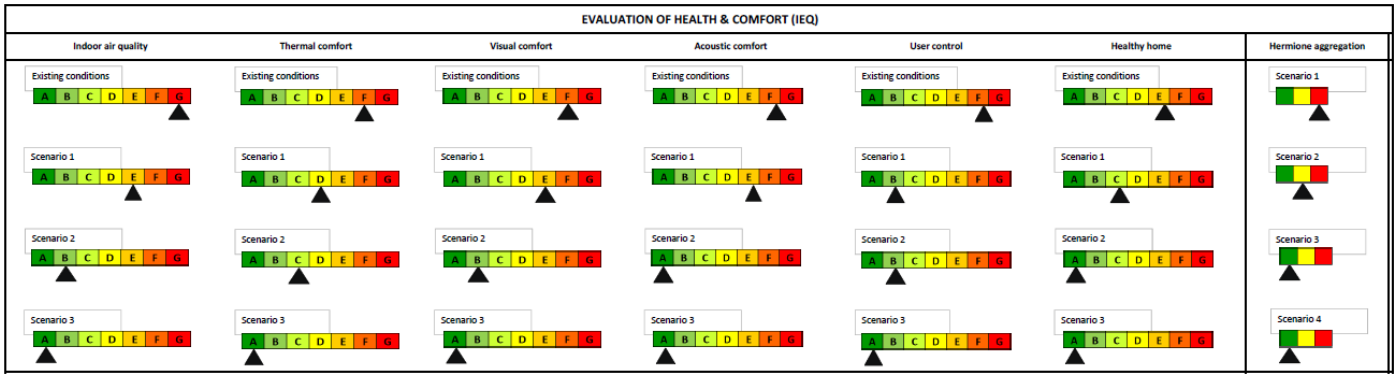


Figure 115: Evaluation and synthesized results for the indoor environment quality for case study No. 1

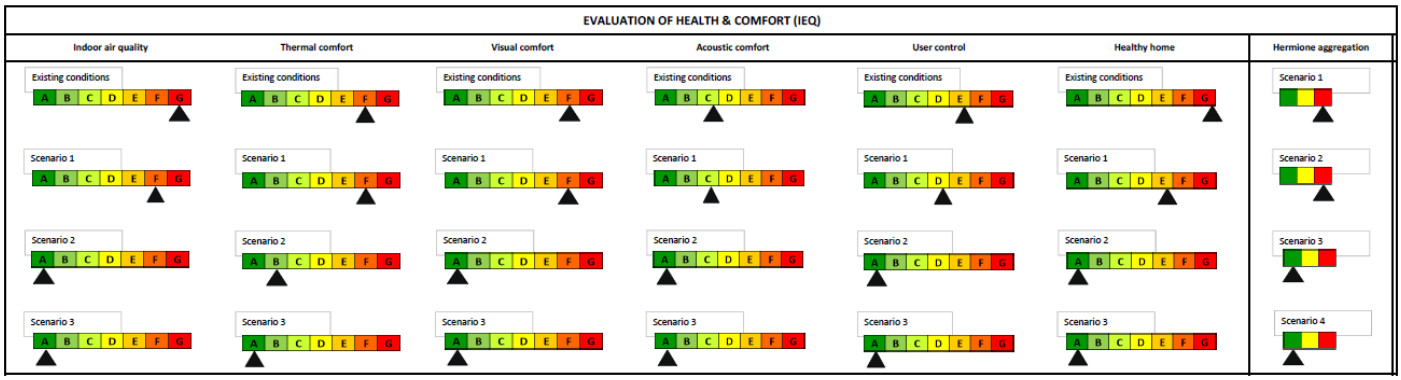


Figure 116: Evaluation and synthesized results for the indoor environment quality for case study No. 2

2.7.2.2.2.3. Synthesis of the criteria dealing with the immaterial values

The synthesis of the evaluations of the criteria dealing with the immaterial values has been done the homeowners directly in their minds. The results for both the house in the existing conditions and the preselected renovation scenarios have been presented as follow (see Figure 117 for case study No. 1 and Figure 118 for case study No. 2).

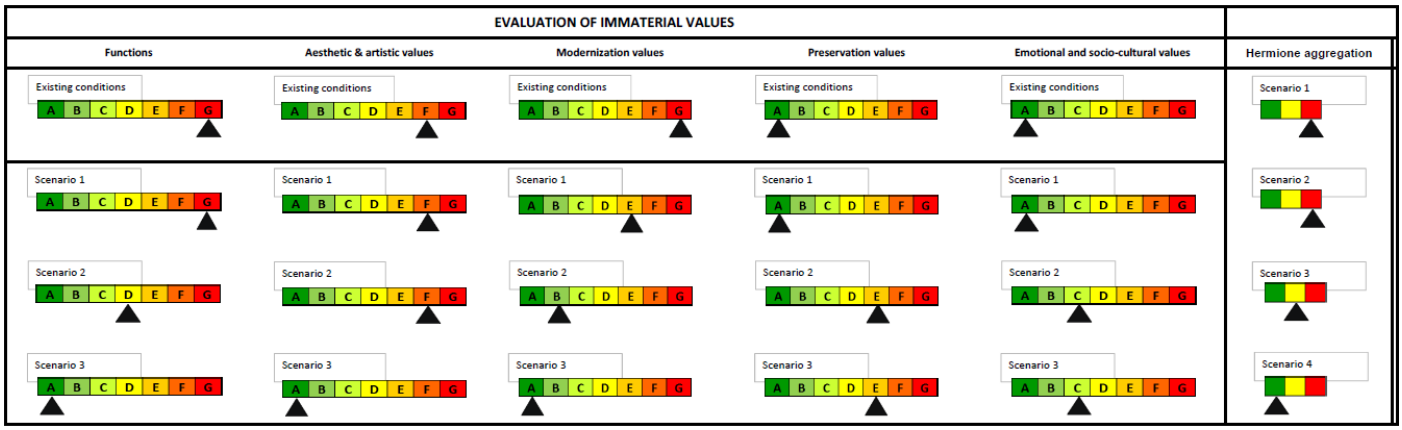


Figure 117: Evaluation and synthesized results for the immaterial values for case study No. 1

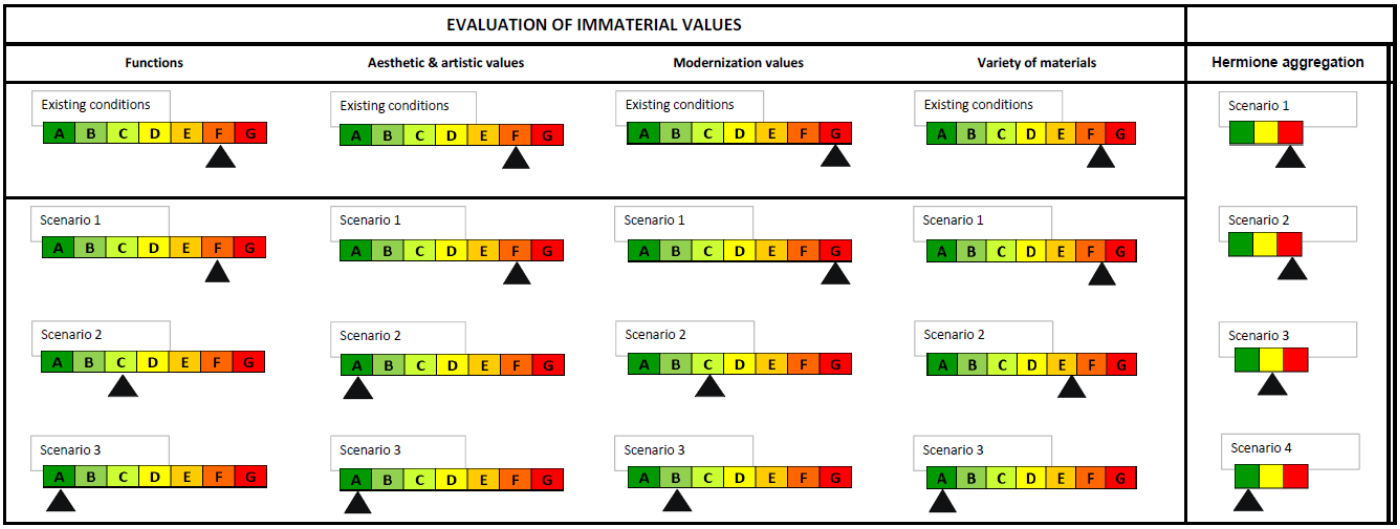


Figure 118: Evaluation and synthesized results for the immaterial values for case study No. 2

2.7.2.2.2.4. Synthesis of the criteria dealing with the economy

The synthesis of the evaluations of the criteria dealing with the economic situation of the homeowners has been done the homeowners directly in their minds. The results for both the house in the existing conditions and the preselected renovation scenarios have been presented as follow (see Figure 119 for case study No. 1 and Figure 120 for case study No. 2).

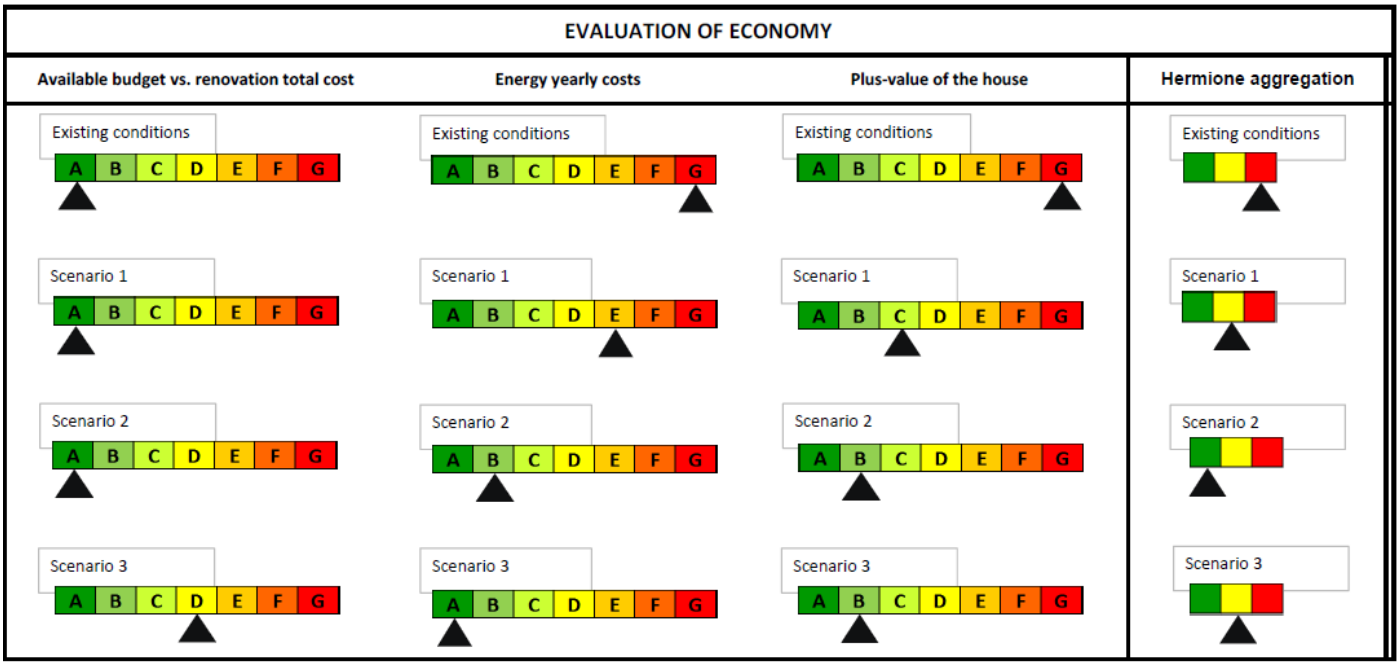


Figure 119: Evaluation and synthesized results for the economy for case study No. 1

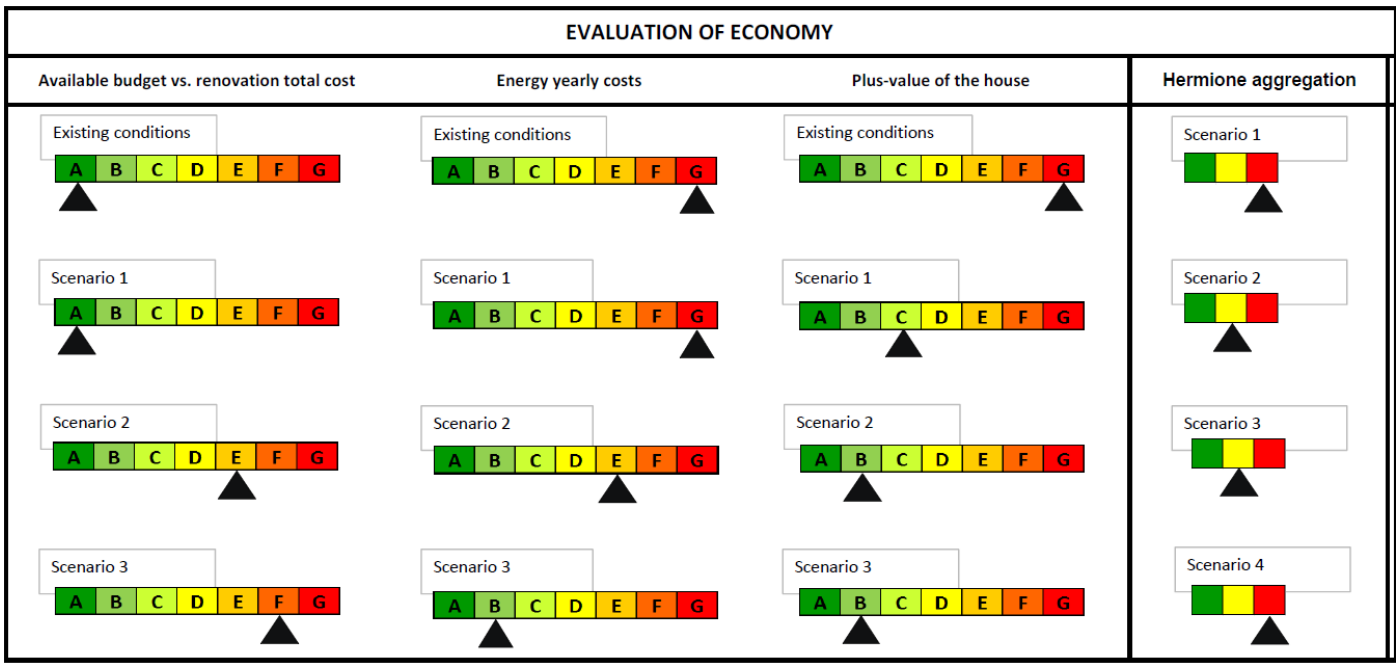


Figure 120: Evaluation and synthesized results for the economy for case study No. 2

2.7.2.2.3. Aggregation of the macro-criteria evaluations into a global evaluation

The aggregation of the macro-criteria into a global evaluation has been done in the homeowners' minds. We are presenting here after the results of the aggregation (see Figure 121 for case study No. 1 and Figure 122 for case study No. 2).

Figure 121: Results of the aggregation of the macro-criteria into a global evaluation for case study No. 1

Figure 122: Results of the aggregation of the macro-criteria into a global evaluation for case study No. 2

2.7.2.2.4. Selection of the most favourable renovation scenario and discussion

The selection of the most favourable home renovation scenario has come from the application of an interactive and constructivist multi-criteria decision making method called Hermione. All sub-criteria and criteria were evaluated quantitatively or qualitatively either by the building expert alone, by the homeowners alone or through a team work between the building expert and the homeowners who agreed on a result together. The same scale has been used all along by the homeowners; moreover, the syntheses and the aggregation were done either in the homeowners' minds or through the use of Hermione aggregation rules. Promisingly, in most cases the result obtained through the synthesis done in the homeowners' minds matched the result that Hermione aggregation rules would have given if used. The exception occurred when dealing with the evaluation of the available budget. Indeed, in both case studies, the evaluation of the available budget vs. the total cost of the renovation was uncertain and depending on factors that the homeowners were not in control of (i.e. whether the bank would loan the amount of money for case study No. 1 and whether their previous house would be sold on time and at which price for case study No. 2). At the end of the process, the homeowners really felt that they were in control of the decision making as a whole, and that they had the final word. From that point, the homeowners were therefore able to select the renovation scenario the most favourable for their needs (or at least to get ready to collect the missing information so they could make a final decision).

Discussion around the house in the existing conditions and the pre-selected scenarios

For both case studies No. 1 and No. 2 and according to the homeowners, keeping the house in the existing conditions is an unfavourable scenario. All evaluations of the criteria are unfavourable (see Figure 123).

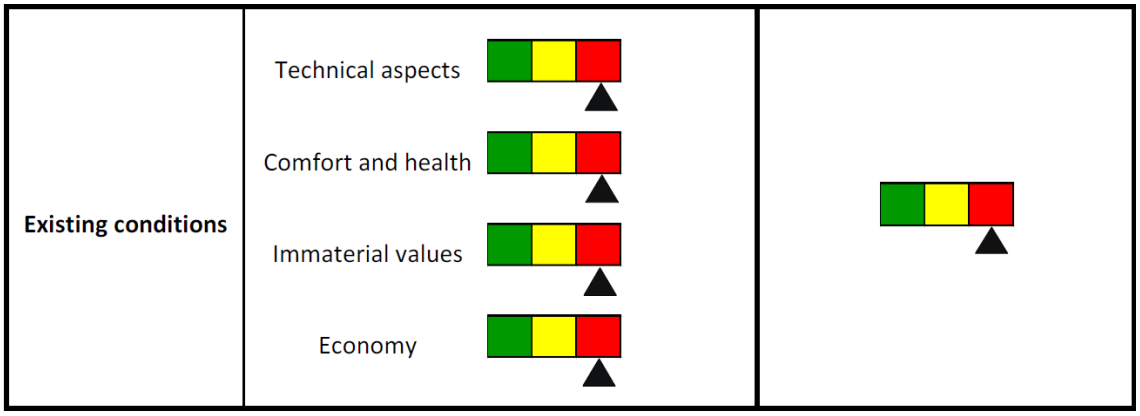


Figure 123: Global evaluation of the house in the existing conditions for both case studies

Upgrading the house to scenario 1 is still unfavourable for case study No. 2 (Figure 125) and not favourable for case study No. 1 (Figure 124). All the evaluations of the criteria are either uncertain or unfavourable:

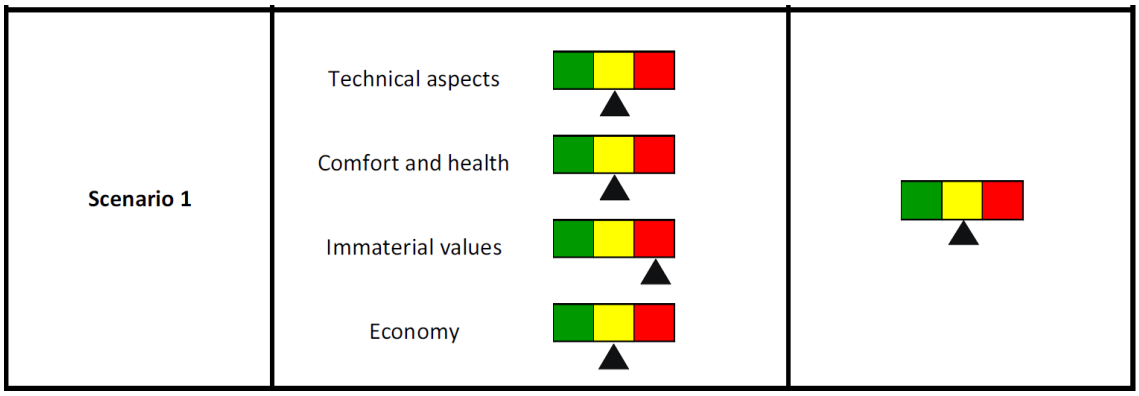


Figure 124: Global evaluation of scenario 1 for case study No. 1

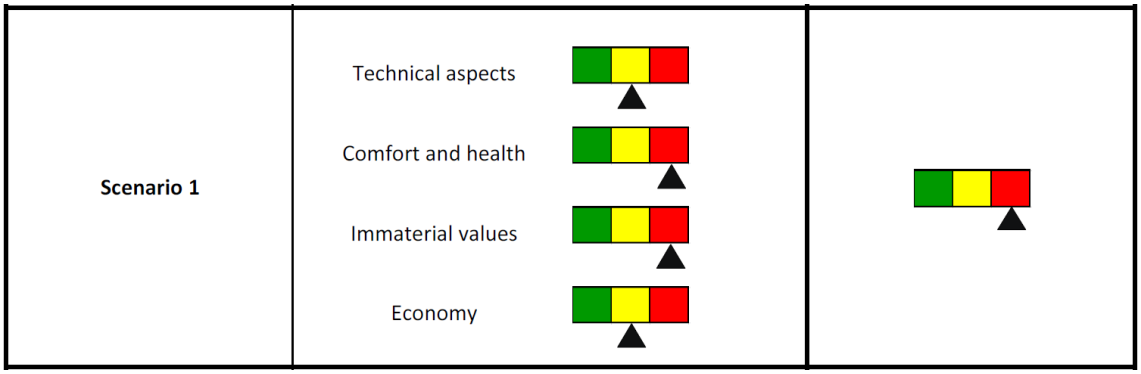


Figure 125: Global evaluation of scenario 1 for case study No. 2

Upgrading the house to scenario 2 is globally favourable under conditions for both case studies. Indeed, most evaluations of the criteria are favourable, however the homeowner in case study No. 1 has to compromise on the immaterial values implying directly her personal feelings (see Figure 126), while the homeowners in case study No. 2 have to compromise on the immaterial values and have to eliminate the last uncertainties on the economy (see Figure 127).

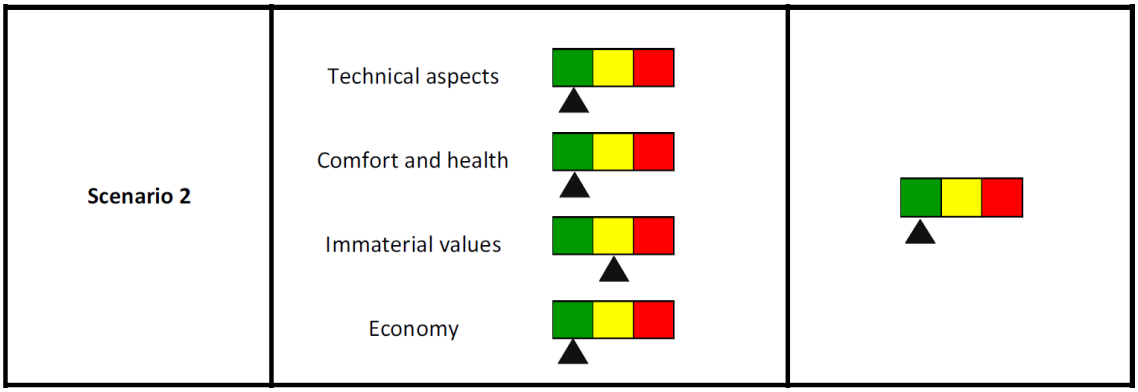


Figure 126: Global evaluation of scenario 2 for case study No. 1

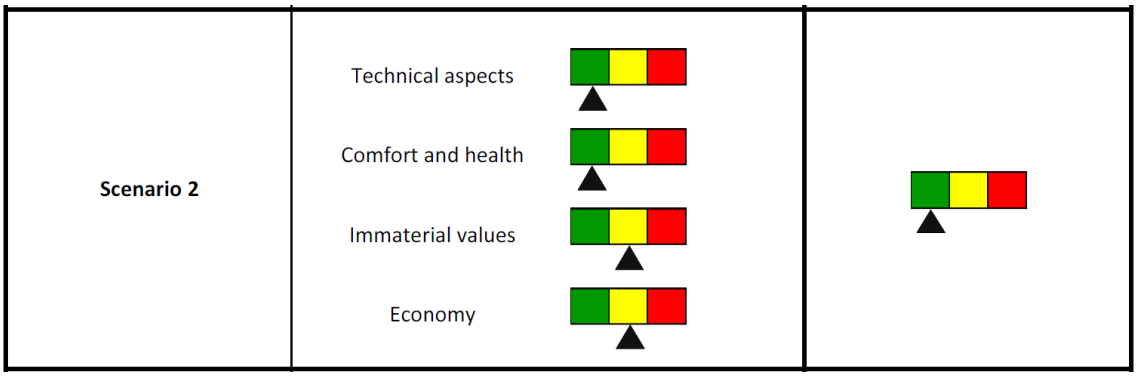


Figure 127: Global evaluation of scenario 2 for case study No. 2

Upgrading the house to scenario 3 is globally favourable for case study No. 1. Indeed, all evaluations of the criteria are favourable (see Figure 128). For case study No. 2, scenario 3 is uncertain. Indeed, it can fall into a favourable global evaluation as into neither favourable nor favourable. The homeowners have therefore to eliminate the last uncertainties about the economy in order to find out if the economic situation is critical or not (see Figure 129).

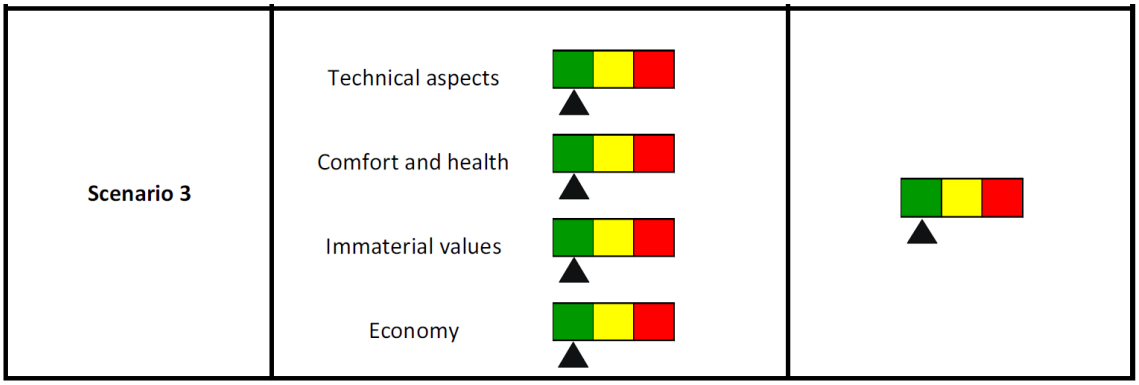


Figure 128: Global evaluation of scenario 3 for case study No. 1

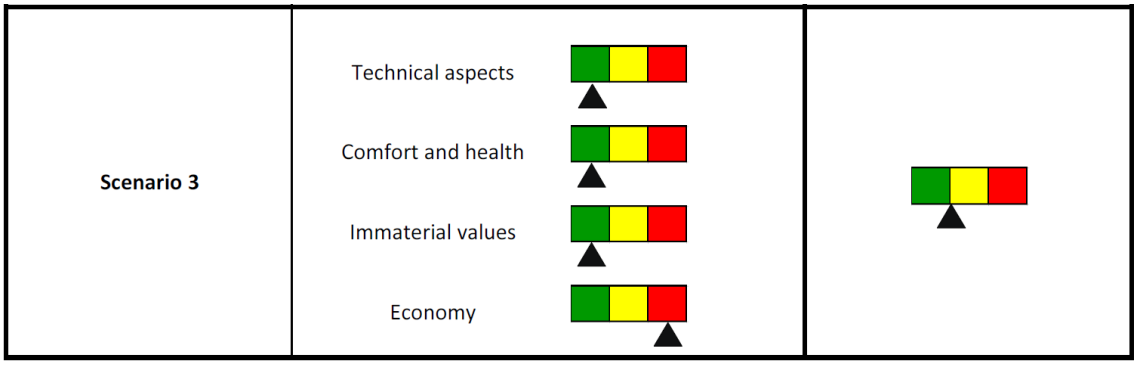


Figure 129: Global evaluation of scenario 3 for case study No. 2

Selected scenario for case study No. 1

In the case of case study No. 1, the first iteration of the Integrated Renovation Process has reduced the set of possible final solutions to the following:

- Scenario 3 after finding an agreement with the bank or,
- Scenario 3 with some punctual measures postponed to a near future (e.g. solar water heater system and photovoltaic panels) after finding an agreement with the bank concerning how to spread out the loan in the coming years or,
- A light scenario 3 in order to find an agreement with the bank concerning the bank loan or,
- A scenario combining scenarios 2 and 3 bring more qualities in terms of immaterial values but still fulfilling the economy of the homeowner or,
- Scenario 2 in the higher range of the alternatives (i.e. scenario 2.3).

The second iteration has helped the team to reduce the scope of possible solutions. It seems that the homeowner (currently deciding) has a preference for the following alternative:

- Scenario 3 or lighter version in agreement with the bank.

Selected scenario for case study No. 2

The first iteration of the Integrated Renovation Process has reduced the set of possible final solutions to the following:

- Stepwise scenario: first step: improved scenario 1, second step: scenario 2 or a combination of 2 and 3:
  - ✓ The scenario combining scenarios 2 and 3 will bring more qualities in terms of immaterial values and may still fulfil the budget limits of the homeowners,
  - ✓ Scenario 2 in the higher range of the alternatives (i.e. scenario 2.3) may not fulfil all the personal wishes (immaterial values) of the homeowners but will be more likely to be in phase with the budget limits of the homeowners.

The homeowners have therefore to eliminate the last uncertainties about the economy in order to make their final decision.

3. Sum up / conclusion

Before applying the Integrated Renovation Process (IRP), the homeowners had an idea of global work to be done in order to improve the conditions of the house (e.g. changing some of the windows or demolishing a part of the wing building, new 1st floor desired, etc.), yet they were uncertain in which works they should undertake and within which budget. Firstly, applying the IRP4homes made the homeowners realize that the houses they have bought is in global poor conditions despite of the renovation work done in the last years (wall indoor surface clearing, cavity insulation in walls and floors, new windows, roof insulation, etc.). The IRP4homes brought progressively knowledge to the homeowners concerning diverse qualities that occupants can expect from a high quality home. It has helped them to realize what they actually need and wish to get as a new home. Thanks to the constructivist and interactive approach, the homeowners showed strong interests concerning the diverse disciplines approached during the process. It seems that the homeowners finally found the information and guidance they needed to feel more confident to decide on a renovation strategy in a near future. It has brought a clearer idea of what budget to expect as well as other economic benefits they can get out of the renovation of their house. They have found out whether they will need to use a one-step or a stepwise renovation strategy in order to reach their final goals. The customized approach, in phase with the homeowners' social and psychological values, seems to have responded to the desire of the homeowners to get a new home responding to their lifestyles, behaviours and personal needs.

Despite the lack of a professional and unified tool IRP4homes has also supported the building expert to be more structured and efficient despite the large amount of disciplines he had to deal with. The multi-criteria building optimisation approach did not motivate the project team to stop at a satisfying level. In the contrary, scenarios with increasing quality states and performance levels have been proposed in such a scheme that the homeowners would get the best for their money. The best alternative is defined, in the IRP, as an alternative bringing a balanced compromise (according to the homeowners and to the building expert) between the three sustainability pillars i.e. the social, environmental and economic parts.

The IRP4homes has leaded the project team to narrow the scope of possible optimized scenarios towards a set of final alternatives; it has however never brought the building expert to make a decision on behalf of the homeowners. The homeowners have now all the tools in their hands as they are currently or will be soon deciding on which renovation strategy to go for.

4. References

Flourentzou, F., Greuter, G., & Roulet, C. (2003). Hermione, une nouvelle méthode d'agrégation qualitative basée sur des règles. 58èmes Journées Du Groupe De Travail Européen D'Aide Multicritère à La Décision, Moscou.

Galiotto, N., Heiselberg, P., & Knudstrup, M. (2014 expected). How to motivate homeowners to invest in sustainable renovation? Unpublished conference proceedings.

National Renewable Energy Laboratory (2014). www.beopt.nrel.gov. Retrieved, 2014.

Statens Byggeforskningsinstitut (SBi) (2012). Retrieved from http://www.sbi.dk/miljo-og-energi/energiberegning/anvisning-213-bygningers-energibehov, 2014.

Strategic Research Centre for Zero Energy Buildings, Aalborg University. (2014). Retrieved from http://www.en.zeb.aau.dk, 2014.

Thomsen, A., & van der Flier, K. (2011). Understanding obsolescence: A conceptual model for buildings. Building Research & Information, 39(4), 352-362.

5. Appendices

5.1. Questionnaire for the occupants of the house

1 How many persons live in the house?

 1 2 3 4 more than 4

2 How old are the persons living in the house?

 0 to 5 6 to 18 18 to 29 30 to 49 50 to 69 70 or more

3 Has someone in the family ever experienced, in your home, symptoms which disappear while being out?

 yes, many times yes, a few times no, never

If yes, which symptoms?

- dry or watery eyes
- stuffy or runny nose
- dry or irritated throat
- feeling of being oppressed
- dry or irritated skin
- headaches
- lethargy or fatigue
- back or shoulder aches

4 Has someone in the family ever experienced asthma problems?

 yes, many times yes, a few times no, never

5 Has someone in the family experienced hay fever or any kind of allergic reaction?

 yes, many times yes, a few times no, never

6 Has someone in the family been bothered by humid air, traces of humidity or condensation in your home?

 many times often sometimes infrequently never

7 Has someone in the family been bothered by bad or stuffy smells in your home?

 many times often sometimes infrequently never

If yes, what are the sources in your opinion?

- smells coming from inside
- smells coming from outside
- smells coming from the toilet
- smells coming from the basement/cellar
- smells coming from the heating system
- smells coming from the ventilation system
- products used in your daily activities
- lack of natural ventilation

- ☐ lack of mechanical ventilation

8 Has someone in the family been bothered by stale or dry air in your home?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

9 Is there someone in the family who smokes inside your home?

☐ yes, many times ☐ yes, a few times ☐ no, never

10 Has someone in the family been bothered by draught or feelings of cold coming from a surface?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

If yes, where was the source in your opinion?

- ☐ windows
- ☐ entrance hall
- ☐ garage
- ☐ external wall
- ☐ mechanical ventilation system
- ☐ heating system
- ☐ ceiling/attic
- ☐ cellar

11 Has someone in the family experienced to be too cold in your home?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

If yes, in which seasons?

- ☐ winter
- ☐ spring
- ☐ summer
- ☐ fall

12 Has someone in the family experienced to be too warm in your home?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

If yes, in which seasons?

- ☐ winter
- ☐ spring
- ☐ summer
- ☐ fall

13 Has someone in the family been bothered by fluctuations of temperatures?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

14 Has someone in the family experienced to have cold feet?

☐ many times ☐ often ☐ sometimes ☐ infrequently ☐ never

15 Has someone in the family experienced the need of switching the lights on late in the morning or early in the evening?

 many times often sometimes infrequently never

16 Has someone in the family experienced the need of more lighting in your home?

 many times often sometimes infrequently never

If yes, in which rooms?

- kitchen
- living/dining room
- bed room
- bathroom/toilet
- entrance hall
- office
- cellar

17 Has someone in the family been bothered by reflects or glare?

 many times often sometimes infrequently never

If yes, what was the cause?

- windows
- artificial lighting
- reflects on the furniture
- reflects on the screen
- other:…

18 Has someone in the family ever wished for a better view to the outside?

 many times often sometimes infrequently never

If yes, from which rooms?

- kitchen
- living/dining room
- bed room
- bathroom/toilet
- entrance hall
- office
- cellar

19 Has someone in the family experienced a feeling of confinement in your home?

 many times often sometimes infrequently never

20 Has someone in the family been bothered by noises?

 many times often sometimes infrequently never

If yes, where did they come from?

- ☐ the traffic circulation
- ☐ other rooms of the same floor
- ☐ upper floor
- ☐ lower floor
- ☐ toilets/bathroom
- ☐ ventilation system
- ☐ heating system
- ☐ other:…

21 In your environment inside your home, what control do you have of the temperature?

☐ no control ☐ very little ☐ somewhat ☐ quite a lot ☐ could not do better

22 In your environment inside your home, what control do you have on renewing the indoor air?

☐ no control ☐ very little ☐ somewhat ☐ quite a lot ☐ could not do better

23 In your environment inside your home, what control do you have of the lighting?

☐ no control ☐ very little ☐ somewhat ☐ quite a lot ☐ could not do better

24 How satisfactory would you describe the accessibility to the different rooms of your home?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

If moderately, slightly or not at all satisfactory, what are the reasons?

- ☐ obstacles in the way of the walking areas
- ☐ rooms too or not enough connected or integrated
- ☐ difficulty to move heavy or voluminous objects
- ☐ difficulty of access for people with reduced mobility
- ☐ other:…

25 Have you ever considered that your home is slightly too small?

☐ yes, many times ☐ yes, a few times ☐ no, never

If yes, what type of room could you envisage to add?

- ☐ kitchen
- ☐ living/dining room
- ☐ bed room
- ☐ bathroom/toilet
- ☐ office
- ☐ garage

26 Have you ever considered that some existing rooms in your home are slightly too small?

☐ yes, many times ☐ yes, a few times ☐ no, never

If yes, which rooms could you envisage to extend?

- kitchen
- living/dining room
- bed room
- bathroom/toilet
- office
- entrance hall
- garage

27 Have you ever considered that some rooms in your home are rarely used except for special occasions or some rooms are not as useful as before and could be improved for a better use?

yes, many times yes, a few times no, never

If yes, what type of room could you envisage to transform or improve for a better use?

- kitchen
- living/dining room
- bed room
- bathroom/toilet
- office
- entrance hall
- garage

28 How satisfactory would you describe the quality of the electrical installations in your home?

very quite moderately slightly not at all

If moderately, slightly or not at all satisfactory, what are the reasons?

- insufficient number of electrical plugs
- improper location of the electrical plugs
- insufficient number of light switches
- improper location of the light switches
- electrical installation functionally obsolescent
- other:…

29 How satisfactory would you describe the quality of the sanitary equipment in your home?

very quite moderately slightly not at all

If moderately, slightly or not at all satisfactory, what are the reasons?

- the water fixtures leak
- some faucets are difficult to turn on and off
- the WC leak
- there is no water in the toilet

- ☐ the hot water takes a long time to come
- ☐ there is rust or mud in the water
- ☐ other:

30 Has someone in the family ever felt unsafe in your home or around your home?

☐ yes, many times ☐ yes, a few times ☐ no, never

31 How important is for you to gather the family together during the family times (dinner, etc.)?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

32 How important is for you to preserve some privacy for each member of the family within your home?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

33 How much of their time does each member of the family spend with the other members of the family in your home?

☐ <10% ☐ 25% ☐ 50% ☐ 75% ☐ >90%

34 How much of their time does each member of the family spend privately (alone or as a couple) in your home?

☐ <10% ☐ 25% ☐ 50% ☐ 75% ☐ >90%

35 How interested may you be to enhance social interaction or make domestic life more pleasurable in your home?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

36 What amount would you be expecting to invest in the retrofit of your home?

☐ up to ~200,000 kr. ☐ up to ~500,000 kr. ☐ up to ~800,000 kr. ☐ up to ~1,000,000 kr. ☐ I don't know

37 How much do you spend in energy yearly (electricity + heat)?

☐ much ☐ quite a lot ☐ somewhat ☐ very little ☐ I don't know

38 How important is it for you to protect your family from ever-rising energy prices?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

39 How important is it for you to reduce your energy yearly spending?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

40 How much do you spend yearly in the maintenance of your home?

☐ much ☐ quite a lot ☐ somewhat ☐ very little ☐ I don't know

41 How important is it for you to reduce your home maintenance yearly spending?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

42 How important is it for you to increase the market value of your home after retrofit?

☐ very ☐ quite ☐ moderately ☐ slightly ☐ not at all

5.2. Structure of the questionnaire with visual support for the usability and the aesthetic values

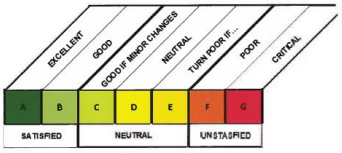
Integrated Retrofit Process

Questionnaire with visual support

Case study October 2013

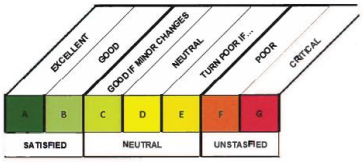
Immaterial values – usability

Room organization – please focus now on the following types of room organization. Which types do you prefer? Evaluate them according to the following scale:



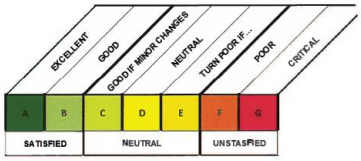
Immaterial values – aesthetic values

Façade – please focus now on the following types of façades. Which types do you prefer? Evaluate them according to the following scale:



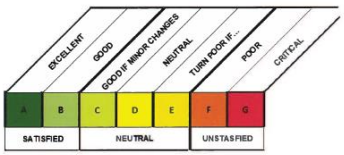
Immaterial values – aesthetic values

Windows – please focus now on the following types of windows. Which types do you prefer? Evaluate them according to the following scale:

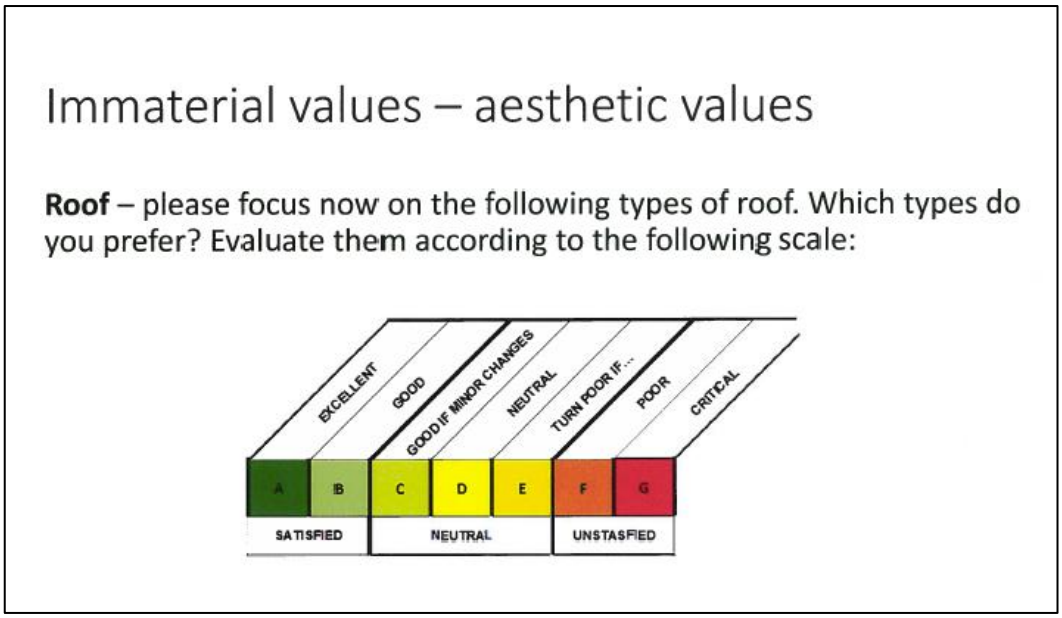


Immaterial values – aesthetic values

Roof – please focus now on the following types of roof. Which types do you prefer? Evaluate them according to the following scale:



5.3. Example of pictures used for the questionnaire with visual support for the aesthetic values (roof)



Photographers: Mathias Sønderskov Nielsen & Nicolas Galiotto

5.4. Degradation and technical obsolescence evaluation diagnosis sheet

5.4.1. Synthesized evaluation

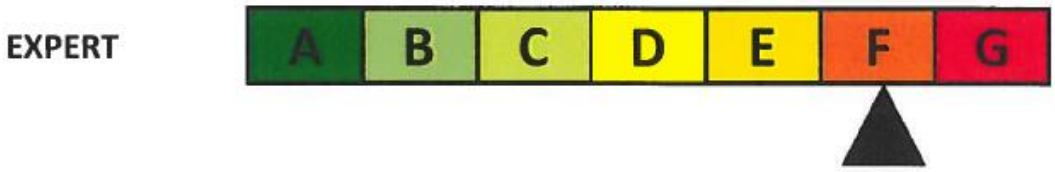
DEGRADATION / TECHNICAL OBSOLESCENCE - Qualitative evaluation criteria

I. Degree of degradation of the building elements
II. Degree of obsolescence of the building elements

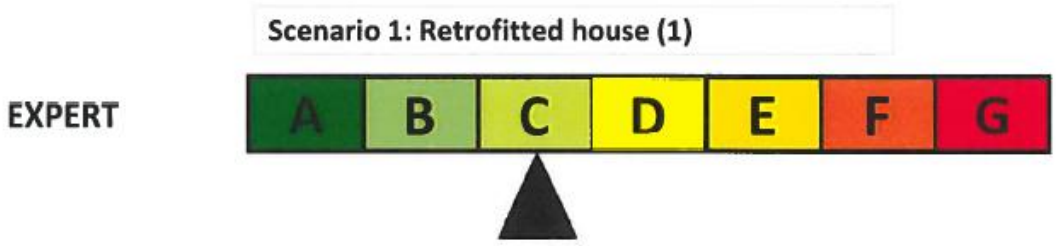
SCALE: Qualitative

A	Excellent - no other condition could be much better
B	Good
C	More than neutral but not good
D	Neutral
E	Less than neutral but not unfavourable
F	Poor
G	Really poor - no other condition could be much worse

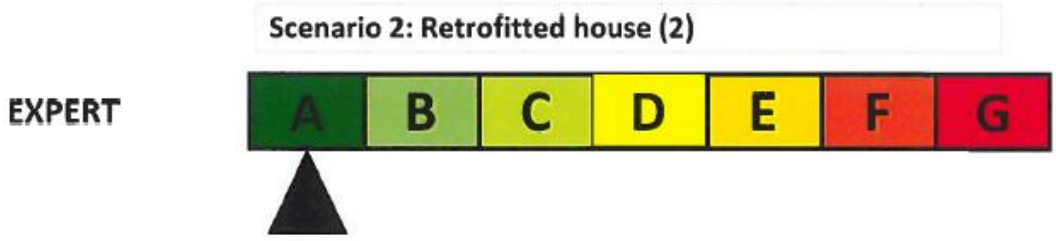
Scenario 0: House with existing conditions



Scenario 1: Retrofitted house (1)



Scenario 2: Retrofitted house (2)



5.4.2. Detailed evaluation

Degradation - Technical obsolescence								Emergency for improvement	
								1	< 2 years
								2	< 5 years
								3	< 10 years
								4	> 10 years
External face of the roof	A	B	C	D	E	F	G		
Roof covering* (e.g. visible holes, breaks, cracks, corrosion)									
Gutters (e.g. slope, corrosion)									
Interfaces masonry/roof covering (signs of moisture and lifting)									
Dormers and gable roof walls (tightness)									
Velux windows (sealing)									
Flashings (corrosion)									
Chimney (e.g. connections, flashings, sooting)									
General condition of the roof (e.g. deformations)									
Internal face of the roof	A	B	C	D	E	F	G		
Condition of the truss									
Potential timber pest damage									
Leakiness (e.g. water stains on the ceiling)									
Chimney (e.g. cleanout doors, sooting)									
Attic installations (e.g. satellite dish, telephone line, ventilation)									
Condition, type and thickness of the existing insulation on the slanted areas and on the tie-beam ceiling									
Condition, type and thickness of the existing insulation on the top floor ceiling									
Exterior walls, windows, doors	A	B	C	D	E	F	G		
General condition of the paint coat									
General condition of the plaster coat									
General condition of the wall base									
Extent and location of cracks									
Signs of rising damp									
Condition, type and thickness of the existing exterior wall insulation									
Condition and type of windows, windowsills, fittings and roller shutter boxe									
Condition and type of exterior doors and terrace doors									
Condition of window and door junctions									

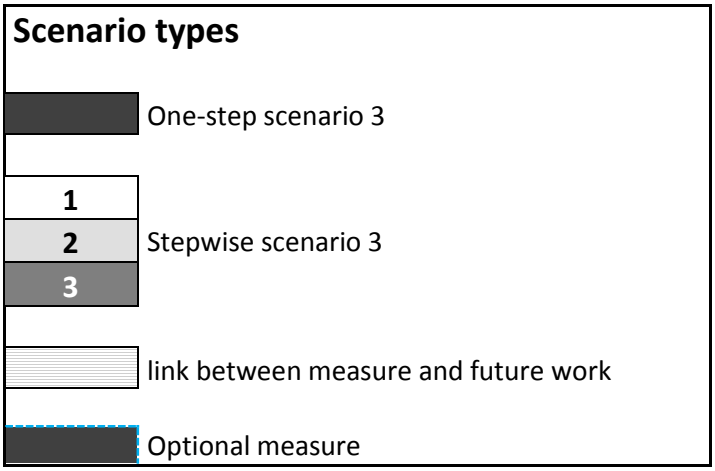
Ceilings above heated areas (top floor ceiling)	A	B	C	D	E	F	G
Type of ceiling (solid or wood)							
Condition of thermal insulation							
Condition and type of impact sound insulation**							
Condition and type of flooring							
Ceilings above cold areas (cellar ceiling, floor slab	A	B	C	D	E	F	G
above the ground, cantilevered floor)							
Type of ceiling/floor (solid or timber)							
Condition and type of thermal insulation							
Condition and type of impact sound insulation***							
Condition and type of flooring							
Interior ceilings (separating floors, mezzanine floors)	A	B	C	D	E	F	G
Type of floor or ceiling (solid or timber)							
Extent and location of cracks							
Condition and type of impact sound insulation							
Condition and type of flooring							
Interior walls	A	B	C	D	E	F	G
Condition and type of paint and plaster coats							
Extent and location of cracks							
Acoustic insulation							
Condition, type and arrangement of interior doors							
Balconies, loggias, terraces	A	B	C	D	E	F	G
Condition and type of balcony or loggia slab (waterproofing, slope, insulati							
Condition and type of terrace (waterproofing, slope, insulation)							
Installations (plumbing and wiring)	A	B	C	D	E	F	G
Condition and type of hot and cold water pipes							
Condition and type of drain pipes and sewers							
Condition and type of electrical cables (electric circuits, power ampli							
location and capacity of the electricity meter							
Earthing and lightning protection							

Heating system and hot water generation	A	B	C	D	E	F	G	
Condition, installation year and type of heating system and piping Condition, type and spatial arrangement of the radiators Condition, installation year and type of hot water generation system and piping								

Scenario 0: House with existing conditions	
Evaluation according to expert A -> G	How to improve the existing conditions? Suggestions from expert
Scenario 1: new propositions	
Evaluation according to expert A -> G	Description of applied measures
Scenario 2: new propositions	
Evaluation according to expert A -> G	Description of applied measures

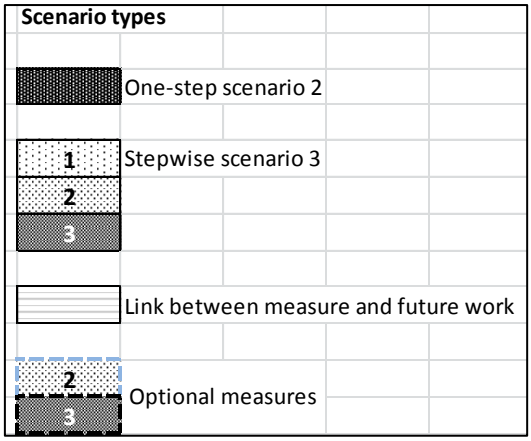
5.5. One-step and stepwise scenarios - “Key thread” case study No. 1

	2014	2017	Later	2014		2017		Later
	ONE-STEP			STEPWISE				
Building envelope								
Scaffolding				1				
Facade insulation				1				
New facade finish				1				
New roof				1		2		3
Roof insulation				1				
Floor insulation				1				
Basement sealing/insulation				1				
New windows				1				
Garage corner demolish/repair								
Technical installations								
Electrical installations				1				
Piping installations				1				
Oil boiler removal/retrofit	Rem			Rem				
Electric. heater removal				1				
Integration of heat pump				1				
Radiant floor heating				1				
Integration of punctual fans				1				
Integration of controlled ventilation				1				
Integration of solar water heater						2		
Integration of solar comp. cylinder				1		2		
Integration of photovoltaic panels								3
Indoor								
Basement removal				1				
Space opening between rooms				1				
Extension of kitchen/bedroom				1				
Refurbishment of bathrooms				1				
New flooring at ground floor				1				
Transformation of first floor				1				
Displacement of the stairs				1				
In between floor acoustic insulation				1				



5.6. One-step and stepwise scenarios - "Key thread" case study No. 2

	2014	2015	2016	2014		2019		Later	
	ONE-STEP			STEPWISE					
Building envelope									
Scaffolding						2			
Wall cavity insulation				1					
Facade insulation						2			
New facade finish						2			
New roof						2		3	
Roof insulation						2			
Floor insulation						2			
Basement sealing/insulation						2			
New windows				1		2			
New first floor						2			
General repair				1					
General demolish				1					
Technical installations									
Electrical installations				1		2			
Piping installations				1		2			
Oil boiler removal/retrofit	Rem			Ret		2			
Integration of air source heat pump						2			
Improv to ground source heat pump						2			
Radiant floor heating						2		3	
Integration of ponctual fans				1					
Integration of controlled ventilation						2		3	
Integration of solar water heater								3	
Integration of solar comp. cylinder				1				3	
Integration of photovolaic panels								3	
Indoor									
Space opening between rooms						2			
Extension of kitchen/bedroom						2			
Refurbishment of bathrooms						2			
New flooring at ground floor						2			
Displacement of the stairs						2			



5.7. Cost details for case study No. 1

Scenario 3.2				
Tiltag	Enhed	Mængde	Samlet	Arbejdsløn i kr.
Exterior walls			**kr. 226.320,00**	**kr. 79.212,00**
Exterior wall insulation	m²	123	kr. 226.320,00	kr. 79.212,00
Basement walls			**kr. 23.730,19**	**kr. 14.617,80**
Basement walls	m²	35	kr. 23.730,19	kr. 14.617,80
Windows/Doors			**kr. 291.363,91**	**kr. 82.616,24**
Rooflights (Demo)	stk.	2	kr. 1.598,68	kr. 1.598,68
Rooflights	stk.	2	kr. 15.267,49	kr. 4.763,46
Existing windows (Demo)	stk.	8	kr. 5.050,80	kr. 5.050,80
New Windows	stk.	12	kr. 128.135,75	kr. 17.426,46
Dismantling doors	stk.	3	kr. 761,88	kr. 761,88
New single doors	stk.	3	kr. 52.805,53	kr. 7.920,83
New double doors	stk.	1	kr. 35.030,06	kr. 3.503,01
Increased window area (Demo)	m²	12	kr. 52.713,72	kr. 41.591,13
Floor separation			**kr. 186.480,08**	**kr. 63.297,66**
Demolition of existing floors	m²	53,4	kr. 26.603,88	kr. 7.183,05
New floor construction				
- Polystyrene	m²	53,4	kr. 39.358,47	kr. 11.020,37
- Concrete	m²	53,4	kr. 15.676,64	kr. 7.038,81
- Mesh reinforcement	m²	53,4	kr. 3.342,31	kr. 1.427,16
Basement ceiling	m²	17,3	kr. 11.387,50	kr. 3.564,29
Basement staircase	m²	9	kr. 5.924,13	kr. 3.649,27
Basement door	stk.	1	kr. 13.120,93	kr. 1.928,78
New 1st floor surface				
- Subfloor	m²	70,7	kr. 24.127,08	kr. 10.447,03
- New flooring	m²	70,7	kr. 46.939,14	kr. 17.038,91
Roof			**kr. 244.401,49**	**kr. 126.619,57**
New Roof				
1st floor demo	sum	1	kr. 15.000,00	kr. 13.500,00
- Insulation	m²	120	kr. 64.064,52	kr. 32.865,10
- Lining Boards	m²	120	kr. 8.605,20	kr. 6.307,61
- Plasterbordsx2	m²	120	kr. 33.760,80	kr. 24.003,93
- Paint work	m²	120	kr. 7.136,40	kr. 5.095,39

- Structural framing	m²	155,7	kr. 30.361,50	kr. 15.180,75
- Plywood for asphalt roof	m²	155,7	kr. 28.259,55	kr. 9.184,35
- Asphalt roof	m²	155,7	kr. 57.213,52	kr. 20.482,44
Interior walls			**kr. 80.909,80**	**kr. 35.844,48**
Interior walls 1st floor	m²	45	kr. 26.530,65	kr. 16.342,88
Interior doors	stk.	10	kr. 47.517,10	kr. 12.639,55
Interior walls ground floor (demo)	m²	15	kr. 6.862,05	kr. 6.862,05
HVAC			**kr. 411.978,39**	**kr. 100.462,53**
Pipe insulation	lbm	10	kr. 1.226,20	kr. 624,14
New thermostats	stk.	5	kr. 6.688,65	kr. 561,85
Wall Feedthrough	stk.	2	kr. 1.200,00	kr. -
Humidity controlled fans	stk.	1	kr. 1.290,33	kr. 384,52
Hood	stk.	1	kr. 4.043,56	kr. 1.694,25
Floor heating	m²	70,7	kr. 21.294,84	kr. 4.535,80
Controlled ventilations	stk.	1	kr. 44.993,64	kr. 6.749,05
Air to Air heat pump	stk.	1	kr. 94.772,17	kr. 11.372,66
Plumbing	sum	118	kr. 53.758,44	kr. 13.439,61
Electrical installation	m²	118	kr. 101.775,00	kr. 35.621,25
Water installation	sum	118	kr. 42.678,24	kr. 19.205,21
Solar water heater	stk.	1	kr. 38.257,32	kr. 6.274,20
Extension			**kr. 133.328,83**	**kr. 59.550,87**
Demo	sum	1	kr. 45.000,00	kr. 40.500,00
New exterior wall	m²	17	kr. 75.768,83	kr. 15.153,77
New floor with floor heating	m²			
- Floor heating	m²	10	kr. 3.102,00	kr. 660,73
- Polystyrene	m²	10	kr. 5.896,40	kr. 1.650,99
- Concrete	m²	10	kr. 2.935,70	kr. 1.318,13
- Mesh reinforcement	m²	10	kr. 625,90	kr. 267,26
Kitchen and bathroom casework			**kr. 75.000,00**	**kr. 10.000,00**
sum			**kr. 1.673.512,69**	**kr. 572.221,15**

Scenario 2.3				
Tiltag	Enhed	Mængde	Samlet	Arbejdsløn i kr.
Exterior walls			**kr. 196.800,00**	**kr. 68.880,00**
Exterior wall insulation	m²	123	kr. 196.800,00	kr. 68.880,00
Basement walls			**kr. 20.634,95**	**kr. 12.711,13**
Basement walls	m²	35	kr. 20.634,95	kr. 12.711,13
Windows/Doors			**kr. 183.181,73**	**kr. 53.061,26**
Rooflights (Demo)	stk.	2	kr. 1.598,68	kr. 1.598,68
Rooflights	stk.	2	kr. 11.744,22	kr. 3.664,20
Existing windows (Demo)	stk.	8	kr. 5.050,80	kr. 5.050,80
New Windows	stk.	8	kr. 65.710,64	kr. 8.936,65
Dismantling doors	stk.	3	kr. 761,88	kr. 761,88
New single doors	stk.	3	kr. 40.619,64	kr. 6.092,95
New double doors	stk.	1	kr. 26.946,20	kr. 2.694,62

Increased window area (Demo)	m²	7	kr. 30.749,67	kr. 24.261,49
Floor separation			**kr. 174.638,92**	**kr. 59.901,11**
Demolition of existing floors	m²	53,4	kr. 26.603,88	kr. 7.183,05
New floor construction				
- Polystyrene	m²	53,4	kr. 31.486,78	kr. 8.816,30
- Concrete	m²	53,4	kr. 15.676,64	kr. 7.038,81
- Mesh reinforcement	m²	53,4	kr. 3.342,31	kr. 1.427,16
Basement ceiling	m²	17,3	kr. 9.902,17	kr. 3.099,38
Basement staircase	m²	9	kr. 5.151,42	kr. 3.173,27
Basement door	stk.	1	kr. 11.409,50	kr. 1.677,20
New 1st floor surface				
- Subfloor	m²	70,7	kr. 24.127,08	kr. 10.447,03
- New flooring	m²	70,7	kr. 46.939,14	kr. 17.038,91
Roof			**kr. 222.610,87**	**kr. 115.532,07**
New Roof				
1st floor demo	sum	1	kr. 15.000,00	kr. 13.500,00
- Insulation	m²	120	kr. 49.280,40	kr. 25.280,85
- Lining Boards	m²	120	kr. 8.605,20	kr. 6.307,61
- Plasterbordsx2	m²	120	kr. 33.760,80	kr. 24.003,93
- Paint work	m²	120	kr. 7.136,40	kr. 5.095,39
- Structural framing	m²	155,7	kr. 23.355,00	kr. 11.677,50
- Plywood for asphalt roof	m²	155,7	kr. 28.259,55	kr. 9.184,35
- Asphalt roof	m²	155,7	kr. 57.213,52	kr. 20.482,44
Interior walls			**kr. 80.909,80**	**kr. 35.844,48**
Interior walls 1st floor	m²	45	kr. 26.530,65	kr. 16.342,88
Interior doors	stk.	10	kr. 47.517,10	kr. 12.639,55
Interior walls ground floor (demo)	m²	15	kr. 6.862,05	kr. 6.862,05
HVAC			**kr. 352.426,23**	**kr. 89.652,53**
Pipe insulation	lbm	10	kr. 1.226,20	kr. 624,14
New thermostats	stk.	5	kr. 6.688,65	kr. 561,85
Wall Feedthrough	stk.	2	kr. 1.200,00	kr. -
Humidity controlled fans	stk.	1	kr. 1.290,33	kr. 384,52
Hood	stk.	1	kr. 4.043,56	kr. 1.694,25
Controlled ventilations	stk.	1	kr. 44.993,64	kr. 6.749,05
Air to Air heat pump	stk.	1	kr. 94.772,17	kr. 11.372,66
Plumbing	sum	118	kr. 53.758,44	kr. 13.439,61
Electrical installation	m²	118	kr. 101.775,00	kr. 35.621,25
Water installation	sum	118	kr. 42.678,24	kr. 19.205,21
Kitchen and bathroom casework			**kr. 75.000,00**	**kr. 10.000,00**
			kr. 1.306.202,50	**kr. 445.582,57**

Scenario 1.2				
Tilting	Enhed	Mængde	Samlet	Arbejdsløn i kr.
Exterior walls			**kr. 38.177,75**	**kr. 11.949,63**
Wall between house and stable	m²	35	kr. 20.033,30	kr. 6.270,42
"Exterior" wall 1st floor	m²	31,7	kr. 18.144,45	kr. 5.679,21

Windows/Doors			**kr. 152.432,06**	**kr. 28.799,77**
Rooflights (Demo)	stk.	2	kr. 1.598,68	kr. 1.598,68
Rooflights	stk.	2	kr. 11.744,22	kr. 3.664,20
Existing windows (Demo)	stk.	8	kr. 5.050,80	kr. 5.050,80
New Windows	stk.	8	kr. 65.710,64	kr. 8.936,65
Dismantling doors	stk.	3	kr. 761,88	kr. 761,88
New single doors	stk.	3	kr. 40.619,64	kr. 6.092,95
New double doors	stk.	1	kr. 26.946,20	kr. 2.694,62
Floor Separation			**kr. 37.872,59**	**kr. 9.627,05**
Basement ceiling	m²	17,3	kr. 9.902,17	kr. 3.099,38
Basement staircase	m²	9	kr. 5.151,42	kr. 3.173,27
Basement door	stk.	1	kr. 11.409,50	kr. 1.677,20
1st floor door	stk.	1	kr. 11.409,50	kr. 1.677,20
Roof			**kr. 40.967,91**	**kr. 25.213,69**
Replacing gutters	lbm	24	kr. 7.425,60	kr. 5.242,47
Replacing drains	lbm	6	kr. 1.161,18	kr. 485,37
Vally gutter repair	sum	1	kr. 12.000,00	kr. 4.200,00
Surface treatment	m²	155,7	kr. 20.381,13	kr. 15.285,85
HVAC			**kr. 123.723,74**	**kr. 40.761,00**
Pipe insulation	lbm	10	kr. 1.226,20	kr. 624,14
New thermostats	stk.	5	kr. 6.688,65	kr. 561,85
Wall Feedthrough	stk.	2	kr. 1.200,00	kr. -
Humidity controlled fans	stk.	1	kr. 1.290,33	kr. 384,52
Hood	stk.	1	kr. 4.043,56	kr. 1.694,25
plumbing in bathroom	smu	1	kr. 7.500,00	kr. 1.875,00
Electrical installation	m²	118	kr. 101.775,00	kr. 35.621,25
sum			**kr. 355.301,46**	**kr. 106.724,10**

5.8. Cost details for case study No. 2

Scenario 3.4				
Tiltag	Samlet		Arbejdsløn i kr.	
Demolition + closure of the construction	**kr.**	**150.000,00**	**kr.**	**75.000,00**
Exterior walls	**kr.**	**251.637,94**	**kr.**	**94.072,37**
Polyurethane insulation	kr.	23.844,56	kr.	10.896,96
Bricklayer work	kr.	6.245,88	kr.	5.633,78
Exterior wall insulation	kr.	179.860,00	kr.	62.951,00
New 1st floor walls	kr.	41.687,50	kr.	14.590,63
Basement walls	**kr.**	**36.532,85**	**kr.**	**18.133,77**
Basement walls	kr.	22.108,88	kr.	13.619,07
Crawlspace walls	kr.	14.423,98	kr.	4.514,70
Windows/Doors	**kr.**	**521.506,09**	**kr.**	**140.556,10**
Dismantling windows	kr.	10.101,60	kr.	10.101,60
Dismantling doors	kr.	507,92	kr.	507,92
New Windows	kr.	85.423,83	kr.	11.617,64
New window sections	kr.	149.173,38	kr.	34.011,53
New single doors	kr.	123.212,91	kr.	18.481,94
New double doors	kr.	70.060,12	kr.	7.006,01
Increased window area (Demo)	kr.	43.928,10	kr.	34.659,27
removing existing window holes	kr.	25.742,80	kr.	18.998,19
workshop windows (Demolish)	kr.	1.894,05	kr.	1.894,05
workshop windows	kr.	11.461,38	kr.	3.277,95
Floor separation	**kr.**	**166.880,73**	**kr.**	**50.284,44**
Demolition of existing floors	kr.	41.350,60	kr.	11.164,66
New floor construction				
- Polystyrene	kr.	48.940,12	kr.	13.703,23
- Concrete	kr.	24.366,31	kr.	10.940,47
- Mesh reinforcement	kr.	5.194,97	kr.	2.218,25
Basement ceiling	kr.	21.464,25	kr.	6.718,31
Basement staircase	kr.	10.732,13	kr.	3.359,16
Basement door	kr.	14.832,35	kr.	2.180,36
Roof	**kr.**	**294.971,36**	**kr.**	**149.740,23**
New terrace roof				
- Insulation	kr.	22.956,45	kr.	11.776,66
- Lining Boards	kr.	3.083,53	kr.	2.260,23
- Plasterbordsx2	kr.	12.097,62	kr.	8.601,41
- Paint work	kr.	2.557,21	kr.	1.825,85
- Plywood for asphalt roof	kr.	7.804,50	kr.	2.536,46
- Asphalt roof	kr.	15.800,78	kr.	5.656,68
- Terrace cladding	kr.	23.244,94	kr.	8.833,08
New Floor separation				
- Lining boards	kr.	3.764,78	kr.	2.759,58
- Plasterbordsx2	kr.	14.770,35	kr.	10.501,72
- Paint work	kr.	3.122,18	kr.	2.229,23
- Subfloor	kr.	17.916,15	kr.	7.757,69
- New flooring	kr.	34.855,80	kr.	12.652,66

New 1st floor roof				
- Structural beams incl. Insulation	kr.	54.491,15	kr.	32.476,72
- Insulation	kr.	28.028,23	kr.	14.378,48
- Lining Nards	kr.	3.764,78	kr.	2.759,58
- Plasterbordsx2	kr.	14.770,35	kr.	10.501,72
- Paint work	kr.	3.122,18	kr.	2.229,23
- Plywood for asphalt roof	kr.	9.528,75	kr.	3.096,84
- Asphalt roof	kr.	19.291,65	kr.	6.906,41
HVAC	**kr.**	**505.495,76**	**kr.**	**156.219,14**
Pipe insulation	kr.	5.579,21	kr.	2.839,82
Floor heating	kr.	35.052,60	kr.	7.466,20
Controlled ventilations	kr.	44.993,64	kr.	6.749,05
Ground source heat pump	kr.	109.997,44	kr.	22.439,48
Terrain work for heat pump	kr.	62.700,00	kr.	31.350,00
Solar water heater	kr.	38.257,32	kr.	6.274,20
Wall Feedthrough	kr.	600,00	kr.	60,00
Hood	kr.	4.043,56	kr.	1.694,25
Water installation	kr.	58.509,49	kr.	26.329,27
Electrical installation	kr.	145.762,50	kr.	51.016,88
Sum	**kr.**	**1.927.024,72**	**kr.**	**684.006,06**

*According to ISOVER.

Scenario 2.3

Tiltag	Samlet		Arbejdsløn i kr.	
Demolition + closure of the construction	**kr.**	**150.000,00**	**kr.**	**75.000,00**
Exterior walls	**kr.**	**209.190,44**	**kr.**	**79.215,75**
Polyurethane insulation	kr.	23.844,56	kr.	10.896,96
Bricklayer work	kr.	6.245,88	kr.	5.633,78
Exterior wall insulation	kr.	147.200,00	kr.	51.520,00
New 1st floor walls	kr.	31.900,00	kr.	11.165,00
Basement walls	**kr.**	**21.163,98**	**kr.**	**9.683,64**
Roughcast repair	kr.	8.800,00	kr.	5.544,00
Paint repair	kr.	824,80	kr.	527,87
Crawlspace walls	kr.	11.539,18	kr.	3.611,76
Windows/Doors	**kr.**	**422.766,80**	**kr.**	**124.144,46**
Dismantling windows	kr.	10.101,60	kr.	10.101,60
Dismantling doors	kr.	507,92	kr.	507,92
New Windows	kr.	65.710,64	kr.	8.936,65
New window sections	kr.	114.748,75	kr.	26.162,72
New single doors	kr.	94.779,16	kr.	14.216,87
New double doors	kr.	53.892,40	kr.	5.389,24
Increased window area (Demo)	kr.	43.928,10	kr.	34.659,27
removing existing window holes	kr.	25.742,80	kr.	18.998,19
workshop windows (Demolish)	kr.	1.894,05	kr.	1.894,05
workshop windows	kr.	11.461,38	kr.	3.277,95
Floor separation	**kr.**	**92.433,34**	**kr.**	**31.800,84**
Cavity insulation over basement	kr.	7.759,20	kr.	4.590,34
Crawlspace ceiling	kr.	47.507,54	kr.	14.869,86

Basement ceiling	kr.	17.171,40	kr.	5.374,65
Basement staircase	kr.	8.585,70	kr.	5.288,79
Basement door	kr.	11.409,50	kr.	1.677,20
Roof	**kr.**	**266.294,62**	**kr.**	**133.625,45**
New terrace roof				
- Insulation	kr.	17.658,81	kr.	9.058,97
- Lining Boards	kr.	3.083,53	kr.	2.260,23
- Plasterbordsx2	kr.	12.097,62	kr.	8.601,41
- Paint work	kr.	2.557,21	kr.	1.825,85
- Plywood for asphalt roof	kr.	7.804,50	kr.	2.536,46
- Asphalt roof	kr.	15.800,78	kr.	5.656,68
- Terrace cladding	kr.	23.244,94	kr.	8.833,08
New Floor separation				
- Lining boards	kr.	3.764,78	kr.	2.759,58
- Plasterbordsx2	kr.	14.770,35	kr.	10.501,72
- Paint work	kr.	3.122,18	kr.	2.229,23
- Subfloor	kr.	17.916,15	kr.	7.757,69
- New flooring	kr.	34.855,80	kr.	12.652,66
New 1st floor roof				
- Structural beams incl. Insulation	kr.	37.580,10	kr.	22.397,74
- Insulation	kr.	21.560,18	kr.	11.060,37
- Lining Nards	kr.	3.764,78	kr.	2.759,58
- Plasterbordsx2	kr.	14.770,35	kr.	10.501,72
- Paint work	kr.	3.122,18	kr.	2.229,23
- Plywood for asphalt roof	kr.	9.528,75	kr.	3.096,84
- Asphalt roof	kr.	19.291,65	kr.	6.906,41
HVAC	**kr.**	**448.014,05**	**kr.**	**145.328,64**
Pipe insulation	kr.	4.291,70	kr.	2.184,48
New thermostats	kr.	8.026,38	kr.	674,22
Controlled ventilations	kr.	44.993,64	kr.	6.749,05
Ground source heat pump	kr.	115.786,78	kr.	23.620,50
Terrain work for heat pump	kr.	66.000,00	kr.	33.000,00
Wall Feedthrough	kr.	600,00	kr.	60,00
Hood	kr.	4.043,56	kr.	1.694,25
Water installation	kr.	58.509,49	kr.	26.329,27
Electrical installation	kr.	145.762,50	kr.	51.016,88
Sum	**kr.**	**1.609.863,23**	**kr.**	**598.798,77**

*According to ISOVER.

Scenario 1.1				
Tiltag	Samlet		Arbejdsløn i kr.	
Demolition + closure of the construction	**kr.**	**100.000,00**	**kr.**	**50.000,00**
Exterior walls	**kr.**	**30.090,44**	**kr.**	**16.530,75**
Cavity insulation Polyurethane	kr.	23.844,56	kr.	10.896,96
Bricklayer work	kr.	6.245,88	kr.	5.633,78
Basement walls	**kr.**	**9.624,80**	**kr.**	**6.071,87**
roughcast repair	kr.	8.800,00	kr.	5.544,00
Paint repair	kr.	824,80	kr.	527,87
Windows/Doors	**kr.**	**34.880,58**	**kr.**	**14.297,62**
Rooflights (Demolish)	kr.	2.398,02	kr.	2.398,02
Rooflights	kr.	17.616,33	kr.	5.496,29
workshop windows (Demolish)	kr.	1.894,05	kr.	1.894,05
workshop windows	kr.	11.461,38	kr.	3.277,95
joints repair	kr.	1.510,80	kr.	1.231,30
Floor Separation			**kr.**	**4.590,34**
Cavity insulation over basement	kr.	7.759,20	kr.	4.590,34
Roof	**kr.**	**10.676,16**	**kr.**	**6.868,53**
Replacing gutters	kr.	8.353,80	kr.	5.897,78
Replacing drains	kr.	2.322,36	kr.	970,75
HVAC	**kr.**	**17.676,80**	**kr.**	**3.761,64**
Pipe insulation	kr.	1.226,20	kr.	624,14
New thermostats	kr.	8.026,38	kr.	674,22
Wall Feedthrough	kr.	1.800,00	kr.	-
Humidity controlled fans	kr.	2.580,66	kr.	769,04
Hood	kr.	4.043,56	kr.	1.694,25
sum	**kr.**	**193.323,98**	**kr.**	**91.458,54**