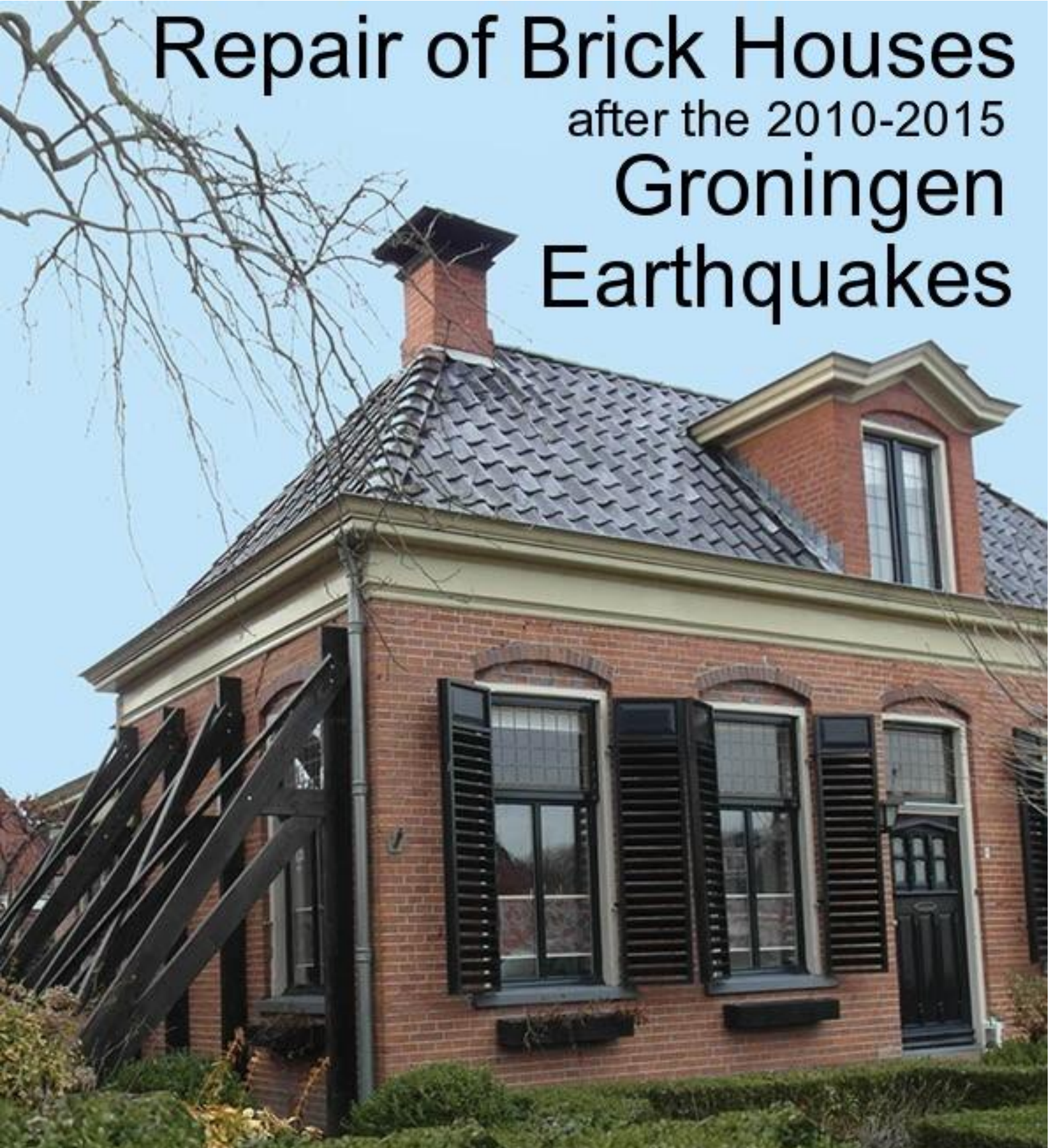
Repair of Brick Houses after the 2010-2015 Groningen Earthquakes



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Part 0 = Introduction

and 12 other chapters in separate files

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This translation has the original figures, but additional explanation is given about the Dutch text alongside these figures.

Photo front page.

This old brick house needs support because of lack of a floor diaphragm that holds the walls together. In addition, the top heavy chimney causes sideway pressure on the wall. Yearly earthquake shocks will eventually result in a further separation of that side wall and eventual collapse.

Picture right. The same building on the other side, with the possible internal reinforcement options listed.

- ✓ *The chimney needs to be replaced by a lightweight copy.*
- ✓ *Support of the dormer window internally is needed.*
- ✓ *Stiffen the roof construction is needed.*
- ✓ *Continued lintel reinforcement above all windows around the building.*
- ✓ *Making the attic floor diaphragm and connecting all the walls.*
- ✓ *Vertical reinforcement of window piers with timber skeleton frame or, make windows from very strong construction glass panels.*
- ✓ *Insulate all the outside walls on the inside after strengthening.*
  Or
- ✓ *Place the entire building on base insulation and insulate it from the inside.*

Photo frontpage by Emilie van Wijnbergen, graduation book: "Earthquake Architecture, balancing conflicting objectives". https://www.tudelft.nl/bk/studeren/studentenwerk/architecture/emilie-van-wijnbergen

[1] National Coordinator Groningen, involved since 2015 in the coordination of the seismic strengthening of houses. The NCG was established after the NAM and later the CVW (Centrum for safe housing) did not make sufficient progress, had restricting criteria about funding repair activities and were publicly regarded both as non-objective entities. The NAM gas exploitation, being the cause of the earthquake damage, and the CVW being under the influence of the NAM. The CVW still being biased about thousands of the damages, causing many arbitration processes by civilians who felt mistreated, while the NAM made over 400-billion-euro profit from the field.

Preface 1.

The main body of this document was produced in 2013-2015 after a firm shock of an induced earthquake, which occurred on 16 August 2012 in Huizinge (PGAg 0,085), in the province of Groningen (The Netherlands) as a result of the natural gas exploitation by the NAM.[2]

The material was intended as training material for building inspectors and contractors involved in the repair and strengthening of the rather weak brick houses that were affected by the short earthquakes.

The Groningen gas field was discovered in 1959, at that time one of the largest natural gas reserves in the world, sized 900 km^2 and having a reserve of estimated 2900 billion m^3 (Nm^3) gas.[3]

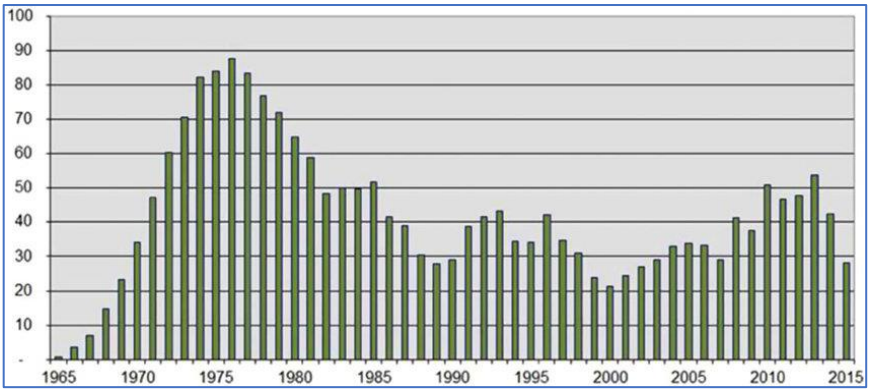

Fig. 1. Annual volume of extracted Groningen gas in billion cubic meters, 1965-2015. In 2016 (not shown), 28 bcm was extracted, as in 2015. The 2017 volume is about 24 bcm. The plan was to stop exploitation by 2030.

The first (earthquake) shocks, caused by the compaction of the sandstone gas-containing sandstone layer, occurred around 1990, but the first shocks sensed by people occurred around 2000.[4] Because the single one-second shocks initially did not cause serious damage to the build environment, gas production was increased again until 2014, one full year after the double shock on 16-08-2012 of Huizinge. This Huizinge earthquake was actually a double shock, causing earth vibrations for several seconds, whereas buildings continued to vibrate for up to 10 seconds.

Gas production was temporarily diminished each time after the early shocks of 2006 and 2008 which were widely sensed. Ever improving analyses of the deeper underground in the 3 km deep positioned and 200 m thick sandstone layer containing gas, indicated that spreading of the production over the dozens of extraction points and with that levelling the internal gas pressure, could prevent larger shocks, keeping the maximum PGA strength under the PGAg 0,1 at which level no houses would collapse or bring the Groningen population in danger. This fact was in strong contrast with the extrapolated PGA prediction by the KNMI in the end of 2013.

[2] Nederlandse Aardolie Maatschappij. A consortium of Shell, Exxon-Mobil and the Netherland Government for the exploitation of the gas reserve. The Exxon-Mobil had delegated the responsibility to the Shell.

[3] https://www.researchgate.net/publication/322549707_Induced_Earthquakes_from_Long-Term_Gas_Extraction_in_Groningen_the_Netherlands_Statistical_Analysis_and_Prognosis_for_Acceptable-Risk_Regulation_Induced_Earthquakes_from_Long-Term_Gas_Extraction_in_Gr/figures?lo=1

[4] The Netherlands population is not familiar with tectonic earthquakes that are far stronger than the induced earthquakes, but also last much longer than the usually one-second shocks of the Groningen induced quakes.

Since 2013 an extensive building repair and strengthening programme was established, but not implemented as national KNMI scientists[5] projected a more than 100-fold increment of the strength of the shocks/earthquakes with a five-fold stronger PGA-acceleration.[6]

While the 'Huizinge' shock was only PGAg 0,085 these scientists predicted serious earthquakes with PGAg > 0,4 that would cause the collapse of tens of thousands of the old brick houses in the Groningen province, causing hundreds or thousands of casualties.

This far over-estimation of the PGA or the Richter scale, caused widespread fear and anger among the population and a serious delay in the retrofitting exercise, because of additional research needed and experimental strengthening. Large earthquakes are an unknown phenomena in The Netherlands and building construction did never consider seismic resistance. Especially the old and poorly maintained farms and brick houses in the rural areas of the Groningen province would not be able to withstand any small earthquakes (< PGAg 0,1) without cracks/damage, let alone larger earthquakes (>PGAg 0,2).

The intention and legal obligation of the commercial NAM enterprise was to reimburse the damage and repair costs, but by no means spend more that strictly necessary. This resulted in spending euro 2 on assessment, reporting, processing and arbitration against only 1 euro on actual damage repair or strengthening or compensation of property devaluation of 180.000 houses, adding to the widespread discontent of the people.

Political unrest resulted in the establishment of first a National Coordinator Groningen (NCG) and later in the Institute Mijnbouwschade Groningen (IMG) eventually having over 700 personnel, most of them lawyers that focussed on building repair, while the NCG focussed on seismic strengthening. Since the mayor shock of Huizinge 16-08-2012 about 80.000 damage reports were filed till 2020, several of them as re-occurrence or for more severe damage. Re-occurrence of damage presented itself regularly as many early repairs where cosmetically without any (seismic) strengthening. Spending euro 2 on reporting, processing and arbitration continued against only 1 euro on actual damage repair.

An extensive social assessment report of the Rijks-Universiteit Groningen (RUG) of many mentally stressed people caused additional social unrest, fuelled by action groups and the press, and continued discontent about the stingy repair progress. This resulted in February 2021 in the establishment of a Parliamentary Commission Earthquakes Groningen which interviewed dozens of managers, leading persons and politicians who were involved in the gas exploitation decision making since 2010 and the damage settlement, resulting in a 2000 pages report in February 2023.

The Parliamentary Commission's report clearly outlined the disputable actions at many management and political levels but failed to analyse the determining and long-lasting effect of the faulty over-estimation of the PGA by the KNMI.[7]

The details of the misleading PGA proposed in the end of 2013 by the KNMI and accepted by the NAM since, are not part of this retrofitting-focussed report but indicates that induced earthquakes need another assessment than tectonic earthquakes and building codes should consider the differences.

[5] KNMI = Royal Netherlands Meteorological Institute, the traditional authority on earthquakes.
[6] The Peak Ground Acceleration is the force that affects the buildings and mentioned in all international earthquake codes for building construction. The PGA is stronger by shallow earthquakes. However, the overall earthquake strength needs to be many times stronger to increase the acceleration.
[7] The Parliamentarian Commission was several times presented with information about these subject, but possibly because of lack of subject knowledge was not able to incorporate the information.

Preface 2.

Due to the recurring earthquake shocks, the ridged brick houses in the province of Groningen have suffered a lot of damage in the recent period since the infamous earthquake shock of 16 August 2012, in Huizinge. Since 2014, a National Practice Regulation has been produced, the NPR 9998:2015, based on the already existing Eurocode 8 dealing with seismic calculation methods. The Eurocode 8 has a national Annex with the seismic map of each European country. For The Netherlands this map was redrawn in 2013 with the proposed PGAg 0,42 at the epicenter. Based on this guideline, the engineering firms set to work to calculate whether the 250,000 homes in the affected earthquake area of Groningen were sufficiently robust against future proposed maximum earthquakes with a PGAg 0,42 and later to PGAg 0,36, or whether they needed to be reinforced or replaced. It became immediately clear that the proposed level of that NPR-Annex was extremely 'over-safe', requiring a quarter of a million houses to be strengthened. These PGAg calculation values were significantly adjusted to lower accelerations between 2016 and 2018. This was called 'progressive insight'. With an annually reduced natural gas output since 2017 and the levelling of the gas-reserve pressures in the sandstone layer, the earthquake shocks became less in strength and less frequency.

In 2019, in consultation with SodM, the Minister of Economic Affairs Eric Wiebes, decided that the production of natural gas from the Groningen gas field should stop completely by October 2022. The Netherlands must therefore use less natural gas and better insulate the houses as well as develop other resources of renewable energy.

In 2020, however, many cracks remain visible in over 25,000 homes that were incurred by earthquakes and other causes since 1990. These are the issues to which much attention is paid in the twelve chapters of this document series. This information was already largely produced by me in 2014.

The accelerated warming of the climate requires a reduction in CO_2-emissions worldwide, as also laid down in the Paris agreement 2015/2016. Poorly insulated homes produce large amounts of CO_2-emissions for heating during cold days. When the walls of a house need to be seismically strengthened, repaired and cracks removed, it is wise to properly insulate those walls at the same time. To do such in two separate phases, is double work and double costs. All of the repair and strengthening work will be carried out by contractors and financed by the NAM/NCG/IMG. The restoration/repair or strengthening must therefore be combined with the energy conservation in a sustainable manner.

When the homeowner receives from 2020 and onward a financial compensation for structural damage or property devaluation, he/she will have to decide how the money will be spent. To strengthen and make the home more sustainable, the homeowner will want to know what needs to be done and how it should be done. After all, the homeowner must then direct the building contractor.

Nine years ago, I developed more than 1000 pages of information for secondary vocational education and training of damage inspectors in an easy readable format than the NPR 9998. With this following document series, I have now organized the text into a dozen chapters and only 500 pages. This version contains international knowledge in the field of earthquake-resistant construction, combined with knowledge about typical Dutch housing design in brick masonry. I have tried to make the information understandable for the homeowners, construction managers, architects, engineers, construction workers and Do-It-Yourselfers.

I hope this work can contribute to a better understanding of the effect of the light earthquakes and helps in good decision-making about making homes in the province of Groningen and other areas where induced earthquakes occur more environmentally sustainable.

Sjoerd Nienhuys seismic engineer. March 2023

Summary and Reader's Guide

The chapters have Internet references and links to research the source and learn more. The Dutch book and the individual 12 chapters are also available on www.nienhuys.info .

Chapter 1: Terms and Abbreviations. This chapter is an ALPHABETICAL LIST explaining the most common concepts related to the Groningen gas field and induced earthquakes.

Chapter 2 is about the **Building Shape** and the different typologies present in the province. Each typology has its own problems with earthquakes and needs its own particular solutions.

Chapter 3 is about **Chimneys and Gable tops** that pose a high risk. All unused chimneys can be removed for climate reasons. Due to architectural considerations, lightweight models can be used instead.

Chapter 4 is about **Foundations** and **Chapter 5** about **Base-isolation**. Vibrations that cannot be felt by humans can lead to subsidence and building damage. A good foundation is necessary for a sustainable building. Especially the brittle masonry buildings and monuments are strongly affected by seismic shocks, causing many cracks. Avoiding this entirely only the expensive Base-isolation is an option. Not applying Base-insulation may require repeated reparation and strengthening actions.

Chapter 6 is about **Strengthening walls. Chapter** is about **7 Lintels**, being components of the walls that require strengthening, especially when large windows are present. These walls require to redistribute the lateral earthquake forces back to the foundations.

Chapter 8 is about Floor Diaphragms and **Chapter 9** is about **Roofs** and deal with those building components that hold the building together and redistribute the lateral forces over the walls. Especially the outer shell of the buildings, walls and roofs are an important factor in both (seismic) reinforcement and energy conservation.

Chapter 10, the Large Truss Barn, indicates that different technical aspects are involved here than in house construction and these must be remedied in their own way. These large and old barn trusses and constructions are typical and historic elements of the Groningen province. Making these often-abandoned large barns sustainable is only possible if there are economic uses for these buildings that guarantee an economically viable use. When Groningen is no longer a region with a shrinking population and the large truss barns are used productively, they can be made more sustainable and maintained.

Chapter 11 is about **Three Typical Examples** of what not to do but what still happened in 2015 due to the over-amplified PGAg according to the 2014 seismic rules of the NR 9998 with the exaggerated seismic map. Examples of demolished buildings, bad analysis and poor decision making.

Chapter 12 is about **Sustainability.** This chapter gives an introduction to making a home more environmentally sustainable, including some information about insulation and heat pumps. The first page of the website www.nienhuys.info has more detailed information in Dutch about these aspects.

Many of the homeowners do not have the funds to make their homes thermally or life-cycle-resistant. Making the houses only structurally (seismically) sound without making them more sustainable is not wise. The repaired houses need also to be made future-proof in other ways, such as with excellent thermal insulation and with heat-pumps with low energy requirements.

Preliminary thoughts and propositions

On the 6th of November 2020 as a response to a new Policy Agreement it was agreed to allocate budget of 1.5 billion euros for the retrofitting. The following comments and questions can be asked in response to that Policy Agreement and the budget.

A. There is a big difference between tectonic and induced earthquakes. It is hoped that as a result of the extensive research on induced earthquakes in the province of Groningen, adapted calculation methods will be developed for induced earthquakes, avoiding the massive mishap with the greatly exaggerated PGAg proposed by the KNMI at the end of 2013.

B. Restoring a home/house to strengthen it against future earthquakes, without also addressing it energetically in view of the climate is NOT a good option.[8] The total investment for seismic reinforcement and sustainability must be compared with the costs of demolition and new construction. The CO_2-emissions for new construction materials must be included in the cost calculation and compared to the lower CO_2-emissions for reuse and recycling.

C. Before 2016, reinforcement recommendations were made for 13,000 homes, based on the first old and far too high NPR 9998 values, but also according to the seismically formal concept that the houses 'just-did -not-collapse'. This ‘near-collapse’ concept was unacceptable to the inhabitants as they did not want their property to repeatedly crack and have it repaired or devaluated. Homeowners now need to consider whether they want to implement the latest technical advice to apply fewer reinforcements that do not protect their building against further cracks like the IMG proposes, or still insist on oversized crack preventing strengthening through the NCG.

D. If the homeowner decides to have a seismic recalculation carried out in 2021 according to the 2020 (lower) NPR 9998 PGAg-map, (as per the Policy Agreement) there may be a financial compensation based on that lesser reinforcement advice. Making an average old brick house (150 m^2 floorspace, two stories) energy-thermally sustainable will probably cost at least 30,000 euros.

E. Owners who opt for latest (reduced) seismic reinforcement advice will receive an allowance of 30,000 euros regardless of the outcome of the advice. This includes a compensation of EUR 17,000 for thermal improvement and sustainability. However, in most cases this is not sufficient for making the building additionally thermally sustainable. House owners do not have additional funds.

F. The approximately 10,000 homes with damage reports that have not yet received a reinforcement recommendation from the NCG or IMG by 2021 will receive a subsidy of 17,000 euros for home improvement and sustainability. Here too, the question is which sustainability measures can be taken and how the homeowner can make up for any difference.

G. The new 2021 interactive NPR9998 seismic map indicates for many locations that the maximum falls below the PGAg 0.05 (with a considerable margin of uncertainty). This means that, according to that NPR, reinforcement against 'near-collapse' is no longer necessary. Elementary reinforcement remains necessary to prevent further wall cracking. With more expertise, the homeowner can consult with the contractor and architect about the desirable steps towards sustainability.

The information in these chapters will help the houseowner, architect and contractor.

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[8] The Groningen gas exploitation was initially mainly used for heating the poorly insulated houses in The Netherlands. The effect of the rather cheap energy was that for many years little effort was made to follow the European guidelines on energy labels for houses and improve on the thermal insulation.