Designing an apartment building with an MPG < 0,5

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Abstract

In the past the main focus within the world of real estate was on energy performance; a lot of high quality insulation, many solar panels and a super heat pump make sure the BENG-requirements are met. However since we are achieving the BENG more and more easily nowadays, another aspect is becoming increasingly important: the environmental performance. From 2025 residential buildings have to meet an MPG-value of 0.5 €/m2.year, which is expected to be definitely doable for most of them, except for apartment buildings.

In the near future the designs of apartment buildings need to be adjusted to decrease the environmental effects caused by the materials during their whole lifecycle. This contains the replacement of familiar traditional materials like concrete for innovative biobased materials for example. Besides, these materials should no longer be demolished after 75 years, but be constructed demountable to make sure they can have a second life.

Furthermore form factors will play an important role in this process; lower floor heights, bigger GFA's and more efficiently shaped footprints are needed to receive the required environmental permit in the future. This report is about the feasibility of apartment buildings meeting an MPG-value of 0.5 €/m2.year and the consequences that go with the improvement strategies that are needed.

1. Problem statement

In the Netherlands it is mandatory to adhere to the Building Code, otherwise construction is not permitted. To add or renovate real estate, you need to take the Building Code into account. The Building Code contains rules regarding safety, health, sustainability and usability of the building. Besides it states rules about renovation or demolition. These rules apply to all buildings in the Netherlands, both existing and new(Ministerie van Algemen Zaken, 2023).

One of the requirements stated in the Building Code regards the 'MPG' which stands for 'Milieu Prestatie Gebouwen'(Environmental Performance of a Building). The MPG is one of the most important benchmarks of sustainability of the building and is focused on the use of materials. The lower the MPG, the more sustainable use of materials(Milieuprestatie gebouwen, z.d.).

At this moment a maximum MPG-value of 0.8 is required for all new buildings with a residential function. However in December 2022 the intention was expressed to lower this value to 0.5 on the 1st of January 2025(Arnoldussen et al., 2023). By lowering this value the Dutch government tries to decrease the negative impact of constructions on the environment. According to experts lowering the required MPG-value is necessary to get more sustainable and circular buildings, since not a lot of attention and effort is needed to meet an MPG-value of 0.8(W/E adviseurs, 2023).

At first glance meeting an MPG-value of 0.5 seems doable for most of the buildings(Arnoldussen et al., 2023). The most effective ways to do so are by paying more attention to the MPG-calculation, paying more attention to the used materials and by applying a longer life cycle in the calculation, which will be discussed in this report later. However some of the main aspects that influence the MPG-value are the form factors, because of which 8-19% of the new buildings will have difficulties to meet the new requirements. These buildings have one characteristic in common: they are relatively small. Examples are small land-based homes or apartment buildings(Arnoldussen et al., 2023).

However it is proven to be technically possible to build all types of houses with an MPG-value of 0.5, including apartment buildings(Kamerbrief normering circulair bouwen en standaardisatie uitvraag duurzame woningbouw, 2023). This requires the use of some strategies, one more complicated then the other. Since these strategies may have consequences for factors like the indoor climate and the financial part of the building, it can be questioned if these changes keep stakeholders satisfied. Is it feasible to build an apartment building using the required strategies to meet an MPG-value of 0.5? And if not, what should be done to make it feasible?

2. Relevance

Sustainability is one of the most relevant topics in the world nowadays. The Dutch government wants to contribute to decrease the negative effects on the environment and the Building Code is one of the many instruments they use to do so. The MPG-value is the most important scale to indicate the impact of the building on the environment. The construction sector is responsible for +-38% of the global CO_2-emission and almost 30% of these emissions are caused by the use of materials(Sobota et al., 2022), which makes the construction sector an area where there is still a lot to be gained regarding the influence on the environment.

The Netherlands is facing a growing housing shortage nowadays, due to the fast growing population. Last year the Dutch population grew by 1.25%(Allecijfers.nl, 2023). For that reason the Dutch government set a goal to add 900.000 houses to the current housing stock by 2030. This is a challenging one. Moreover, ⅔ of these houses should also be affordable, which is not always easy since building materials are getting rarer(Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2023) which not only causes high prices but time delays too.

There is a reason this research is focused on apartment buildings. To meet the new required MPG-value of 0.5 from 2025 on, new ways of building are needed to decrease the environmental impact. This is expected to be doable, but it will be more difficult for certain types of buildings than others.

The MPG is a scale that is measured per square meter GFA, which stands for Gross Floor Area(Arnoldussen et al., 2023). The GFA is the total floor area of all floors in square meters including the exterior walls and the installations. Relatively more walls and installations causes an increase in the MPG-value. This is especially the case in small houses, like tiny houses or apartment buildings. With the current housing shortage and need for building a big amount of houses in a short period of time, these types of houses are necessary.

3. Research questions + model

During the research there will be looked into the environmental performance of apartment complexes. Although it is more difficult for apartment buildings to meet the new required MPG-value of 0.5, which will be valid from the 1st of January 2025, there are ways to do so. This will be discussed in the literature review later in this report. However this report will look into the feasibility of these apartment buildings meeting these requirements. This will be done answering the following research question:

3.1 Research questions

Main research question: *How can apartment buildings be designed with an MPG < 0,5 and with what impacts?*
To answer this main question the following sub questions will be answered first:

SQ1: *What are the most influential factors for the MPG?*
To get to know what design choices are needed to meet the required MPG-value of 0,5 €/m2.year, first the most influential factors of a building are identified. This will give an idea of the buttons that are best to turn in improving the MPG, which can help creating improvement strategies.

SQ2: *What strategies are needed for apartment buildings to meet an MPG-value of 0,5?*
Based on the information provided in the answer to SQ1 multiple strategies will be listed that are needed to meet the future required MPG-value of 0,5 €/m2.year. By picking the most influential factors of the building on the MPG, the most efficient strategies can be chosen.

SQ3: *What are the impacts of these strategies for the costs and the living environment?*
After determining the needed strategies to meet an MPG-value of 0,5 the impact of them is studied. There will be looked at the impact on both the costs of the building and the impact on the living environment. Does the quality for the user remain the same?

3.2 Definitions

This research is going to study how an apartment building can be designed in such a way it meets an MPG-value of 0.5 and thereby will meet the requirements regarding the MPG after 2024.
In this research there will be focused on two important stakeholders: the developer and the user. The stakeholders that are being studied in this research are described below including their important values

<u>Developer</u>
The developer is the party which is responsible for coming up with a feasible plan and design. To find an investor willing to pay for a project they need to think of a viable business plan, which includes the guarantee that there is enough demand for the dwellings and the future income is higher than the costs. Furthermore it should be a plan that is technically possible within a certain period of time.

<u>User</u>
When the apartment building is finished it is expected to be used for at least 50 years. During that period it generates money out of rents or sales (usually) paid by the users of the apartments. In general the apartment will only be rented if the rent price is fair in comparison with the quality of the apartment and the quality of living inside.

The building itself is one of the most important factors deciding the quality of living in the apartment. The living environment at home, contain for example the amount of noise, daylight and quality of air, affects the mental health of its residents(Rautio et al., 2017). Besides the density of units and aesthetics of the neighborhood were influential for mental health or even causes for depression.

<u>MPG</u>
As mentioned before the MPG is an instrument that is only used in the Netherlands. In other countries there are comparable instruments, for example the Leadership in Energy and Environmental Design-rating system(*LEED rating system | U.S. Green Building Council*, n.d.) and the Building Research Establishment Environmental Assessment Method(McPartland, 2016). Since this research is focused on the MPG and there is no internationally recognized term which works the same way, this term will be used in this report.

3.3 Conceptual model

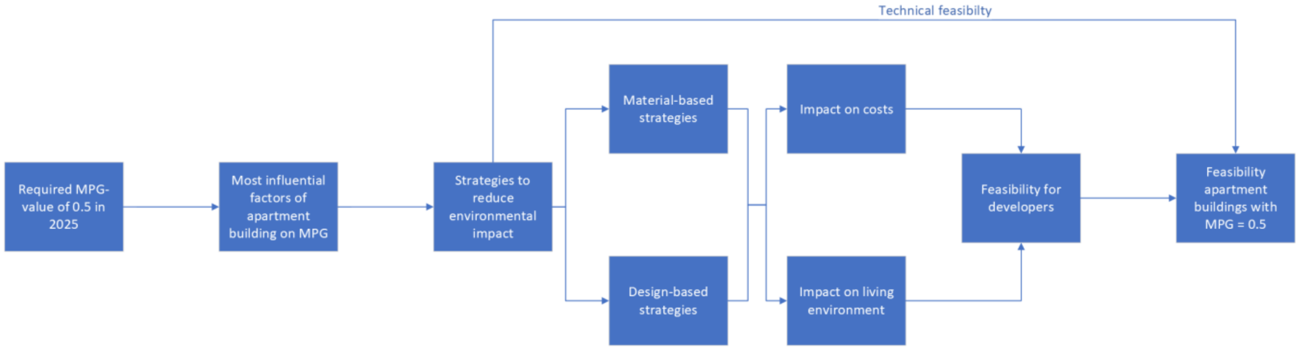

Figure 1: Conceptual model(own work).

3.4 Possible case studies

To get a better idea of what strategies are needed to decrease the MPG-value to 0.5 or lower, there will be picked case studies that either meet these requirements or come close. This can hopefully be done by contacting construction companies, but on the internet there are some possible case studies that are described below.

Draaischijf, Milsbeek. MPG = 0.42 €/m2.year

This project of the company Lister Buildings is located in Milsbeek and is built for people in need of care within the social rent and mid-priced sector(*Het andere wonen Milsbeek - Lister Buildings*, z.d.). It contains 20 apartments with a total GFA of 1485 m2. The building is modular built and is fully circular and demountable. It is built of CLT and has a wooden façade. It has an MPG-value of 0.42 excluding solarpanels; if they are included the MPG-value rises to 0.59(Lente-Akkoord 2.0, 2023). This difference is what makes this an interesting project for this research.

Xylino, Almere. MPG = 0.65 €/m2.year

In the neighborhood 'Homeruskwartier' in Almere there is an apartment building being built containing 103 apartments with an average GFA of 95 m2 per dwelling. For this 5-floor building a modular wooden system was used with wood and other bio-based materials only. This results in an MPG of 0.65 €/m2.year, but although this does not meet the future required value of 0.5, it could be interesting to study this project because of its large amount of dwellings. Its special shape makes it even more interesting(*Xylino | de Alliantie*, z.d.).

Switi, Amsterdam South-East(apartment building phase 3c). MPG = 0.46 €/m2.year

This regards an apartment building that is part of a bigger project with 220 dwellings in total. This building has an MPG-value of 0.46 excluding extra solar panels. If the extra solar panels were included, the MPG would be 0.54. The 45 apartments in this building have a total GFA of 4364 m2(Lente-Akkoord 2.0, 2023) and are divided among 8 floors. For this building CLT-modules and wooden-frameworks were used. Wood fibre insulation and a façade cladding of wood makes it even more sustainable.

4. Research method

During this research multiple different methods will be used to answer the research questions mentioned earlier. This report contains a big part of literature research, which was done to get an overview of the current knowledge about this topic. Various studies about strategies to improve the MPG-value of a building are already done in the past, but there are still continuously new ways in development to decrease the environmental impact even more. This knowledge can be useful to find out how to make apartment buildings with an MPG that meets the future required value of 0.5 feasible.

4.1 Plan of approach per research question

Subquestion 1, '*What are the most influential factors for the MPG?'* is a sub question that will be answered to show the influence of certain factors of the building. For example how big is the difference regarding the MPG-value when using a different material? Or what happens to the MPG when increasing the dimensions? To find out these influences case studies will be done on existing projects. By comparing the MPG-calculations and the factors of these projects, possible patterns could be recognized. In the end the factors will be ranked on their influence. This answer can help by creating strategies to lower the MPG.

Subquestion 2, '*What strategies are needed to meet an MPG-value of 0,5?*' is about getting to know how to technically make an apartment building with an MPG-value of 0.5. What strategies are needed and which ones can be combined to do this? For this question interviews will be done with sustainable-building experts, to find out possible new ways to decrease the environmental impact. Furthermore by using case studies the result of combining strategies can be studied. These case studies can hopefully be found via the database of the graduation company, but to get a fair and reliable image there will also be studied projects of other companies. As a result of this sub question a list of strategies and solutions will be made including their effect. Besides there will be at least one possible combination of these strategies that is needed to meet an MPG of 0.5. Based on this combination a prototype of an apartment building will be designed, including an MPG-calculation to prove it meets the required MPG-value. Additionally it could be interesting to look at the combination that makes the MPG-value as low as possible.

Subquestion 3, *'What are the impacts of these strategies for the costs and the living environment?'*, is focused on the consequences of using the strategies determined in SQ2. First of all there will be looked at the impact on the costs of the apartment building. If the costs would be higher, it will be more difficult for developers and contractors to build apartment buildings meeting an MPG-value of 0,5.

Furthermore the impact for the user will be studied. What influence does the use of certain materials have on the living conditions and quality of life in the apartment? Or what does a possible change in the form of the dwelling mean?
To get an answer to this question both *prototyping* and *interviews* will be used. By designing an apartment building containing the strategies needed to meet the MPG-value of 0.5, the consequences can be discussed with developers to test whether they expect there will be demand for them despite the used strategies.

4.2 Type of study

During this research there will mainly be used explorative studies and qualitative studies. This research is focused on *how* apartment buildings with an MPG-value of 0.5 can be feasible and therefore qualitative information is needed. Using interviews and case studies more in-depth information about the consequences of possible strategies to decrease the MPG-value can hopefully be found. Besides, there could be found other less known strategies and ways to improve the environmental performance of apartment buildings that may influence the costs and/or livings environment differently. Since this topic was not fully studied in-depth yet and there will be searched for new ideas to improve the MPG, this will contain explorative research too(Elman, Gerring & Mahoney, 2020).

4.3 Methods and techniques

Different methods and techniques will be used to answer the research questions. In the plan of approach in paragraph 6.1 some of them were already explained. Below the techniques to be used are explained more in detail.

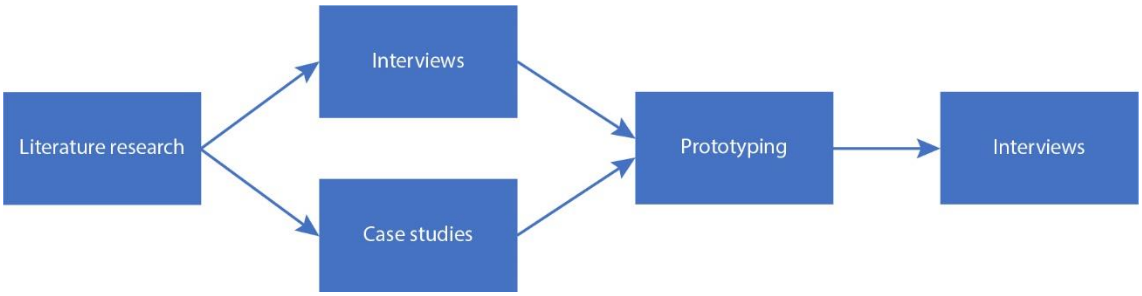

Figure 2: Methodology model(own work).

4.3.1 Interviews

During the search for less known strategies to decrease the environmental impact of interviews will be conducted with experts. Furthermore their experience with case studies may help.
To get the optimal result out of the interviews it is important to talk to the right people. The goal of the first interviews is to get information about strategies to decrease the environmental impact of buildings, that are not available through literature studies. Therefore the interviews will be done with experts or researchers who are looking for new strategies. People from for example W/E adviseurs or someone from the organization of the Lente-Akkoord are working on the environmental impact every day and can probably give useful information. Within the graduation company there will probably be people within the sustainability-department too who are interesting to talk with. However it is important to talk to people from other companies too, to not be biased.

4.3.2 Case studies

To find out what is needed to meet an MPG-value of 0.5 case studies will be done. This way the most influential factors of the building can be identified. The case studies will be existing recent projects of apartment buildings that have an MPG-value of 0.4 to 0.6. These can hopefully be found via companies and on the internet.

In paragraph 5.4 there are already mentioned some examples of possible case studies. These case studies do not only give insight in the needed strategies, but they can also be compared to see what can be the deciding factor when trying to reach 0.5 €/m2.year.

4.3.3 Prototyping

The case studies can show which strategies are most influential to improve the MPG-value. However it is unknown how the combination of them will work. To find out a prototype will be designed. By developing, evaluating or communicating a concept, design or problem solution ideas are made concrete to learn whether they work and to discover the technical limitations or possibilities(Vogel, n.d.). Since this research is studying the feasibility of quite an unknown concept where multiple strategies are probably be combined, prototyping could be a suitable method.

4.4 Data Analysis

During the research different types of data will be collected. First of all interviews that are held will be recorded, with permission of the interviewee of course. These interviews will be transcribed but these transcripts will only be available for the writer of this thesis.

4.5 Ethical considerations

While doing this research a lot of data will be collected, some with confidential information that cannot be shared with everyone. Therefore it needs be clear what is done with the information provided by for example experts or future residents. Ahead of interviews the interviewee will be asked to sign a contract which states the condition of the interview; what will the data be used for? With whom will the results be shared?

4.6 Planning

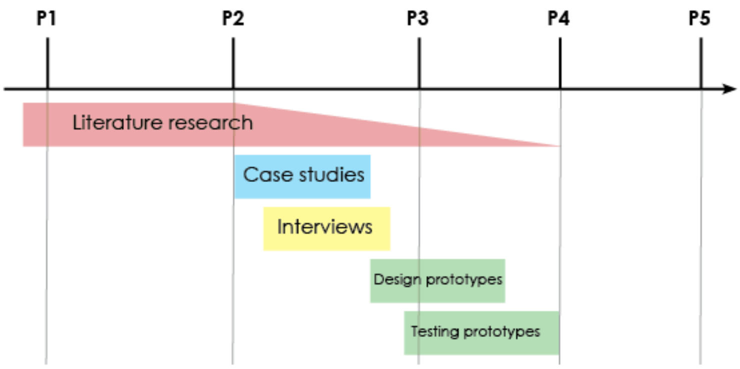

Figure 3: Time schedule

5. Critical overview and main findings from literature and market research

For this research a critical literature research was done. This contained a short study about the definition and function of the MPG, possible strategies to improve it, consequences of these strategies for both the financial part and the users living environment, shortcomings of the current MPG-calculation method and difficulties for apartment buildings. This information is useful to get an image of the current status of the MPG in the Netherlands.

5.1 What is the MPG?

'Nowadays the 'Milieu Prestatie Gebouw'(MPG) is the most important instrument to decrease the environmental impact of newly build housing and offices.' (W/E adviseurs, 2023). Only three years ago, on January 1st 2021, the required MPG-value of newly build buildings with a residential function was reduced from 1.0 to 0.8. The Dutch government had set a goal to decrease this even further to 0.5 in 2030. However, it is currently being considered to implement this change sooner and lower the required MPG value to 0,5 as early as January 2025(W/E adviseurs, 2023).

But what does the MPG mean exactly? The MPG is a scale to measure the environmental performance of a building as a whole(The MPG is calculated by summing up the prevention costs of all materials used in the building. These prevention costs entail all costs that are needed to be made to prevent the environmental impact of these materials during the complete lifecycle of the building(Milieuprestatie gebouwen, z.d). This means that materials that has to be replaced during the lifecycle of the building, should also be taken into account. After summing up these costs the total amount is divided by the buildings lifecycle in years(based on reference projects) and then it is divided by the Gross Floor Area. This gives the MPG expressed in €/m2.years(Milieuprestatie gebouwen, z.d).

To calculate the prevention costs of materials you first need to know the exact environmental impact of those materials. This is calculated using a Life Cycle Assessment(LCA). Based on the LCA an Environmental Product Declaration(EPD), which is a document officially stating the environmental impact, can be linked to a material(Arnoldussen et al., 2023). In the Netherlands these documents are collected and kept in the NMD(Nationale Milieu Database)(Stichting Nationale Milieudatabase, 2023).

The result of an MPG-calculation is a profile containing 11 environmental effects on building level. The most important ones are depletion of raw materials, the effect on global warming and the depletion of the ozone layer(Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken, 2011).

Increasing the MPG has negative effects too. In some cases it has an inverse relationship with the energy performance of the building. A lot of installations and materials that are often used in modern buildings cause an increase in energy performance, but in the meantime they cause more GHG-emissions. For example putting solar-panels on a roof will improve the energy performance since it can produce renewable energy. However, to produce solar panels certain rare and polluting resources are used, which causes an increase in the GHG-emissions. It is estimated that it takes 5 to 7 years to win back these emissions(Lente-Akkoord 2.0, 2023). Another example is the use of a heat pump, which is stimulated a lot nowadays. It can improve the energy performance, but it also has a big ecological footprint which causes a negative effect on the MPG(V an Der Zee, 2023). According to an article in Solar Magazine the effect of the heat pump is too big to even meet the required MPG-value(Solar Magazine, 2023).

One of the most important ingredients of the MPG-calculation is the Life Cycle Analysis. The LCA is a quantitative method to determine the environmental impact of a certain material or product over its lifecycle. This entails the depletion of raw materials, the production of the product, the transport and its impact on the environment during the use. The result of the LCA is the MKI: Milieu Kosten Indicator. Literally translated to English, this means Environmental Cost Indicator(Arnoldussen et al., 2023).

5.2 Ways to improve MPG

Several ways to improve the MPG of a building are already known. According to research done commissioned by the Dutch government, for all types of newly build buildings it is technically possible to meet an MPG-value of 0.5(*Kamerbrief normering circulair bouwen en standaardisatie uitvraag duurzame woningbouw, 2023*). The current required MPG of 0.8 is pretty simple to meet, but to decrease the MPG to 0.5, the building needs more attention(W/E adviseurs, 2023).

In most cases it will not be sufficient to only use one of the available strategies to improve the MPG, but they will have to be combined. Combining different strategies will not always deliver the maximum decrease of MPG for each strategy, since they often regard the same part of the building. The trick is to find the optimal combination(Lente-Akkoord 2.0, 2023).

One of the first things that could be done to improve the MPG is to use more sustainable versions of certain materials. Producers of materials are also constantly trying to improve their own product, for example by producing it in a more sustainable way. Concrete is a clear example of this; used concrete can be the base for new concrete which decreases the environmental impact. In the Netherlands one important condition in recycling, is a clear documentation in the 'Nationale Milieu Database'(Arnoldussen et al., 2023). When redeveloping a building it is also possible to reuse (part of) the construction. Since a reused concrete construction can be less sturdy, it is recommended to combine this with a lighter wood construction. Using recycled constructions can reduce the MPG-value by +- 0,1(Lente-Akkoord 2.0, 2023).
Besides constructive materials there are also individual parts in a building that can often easily be reused, for example doors, window frames, insulation materials, modular walls or stairs. This can decrease the MPG-value with up to 0.5 €/m2.year.

Another way of using material leading to less environmental impact is the use of renewable materials. Bio-based materials like wood, straw or bamboo are resources that are not as rare as other materials. Wood can be applied in the form of a timber frame construction(HSB in Dutch) or as cross laminated timber(CLT). These measures can reduce the MPG-value with +-0,07(HSB) and +-0,15(CLT)(Lente-Akkoord 2.0, 2023). Using wood as façade cladding can be beneficial too. Combining multiple materials can also be an option in creating a more sustainable construction. This is called a hybrid construction. Examples of hybrid constructions are wood/concrete or wood/steel(Arnoldussen et al., 2023).
Furthermore there are studies looking into using recycled wood as an alternative for thermal insulation. Not only wood but also other bio-based natural fibre materials like cork, cotton and hemp have received increasing focus in both research and application, because of their relatively small impact on the environment (Çetiner & Shea, 2018).
Besides recycled materials and existing bio-based materials manufacturers are constantly searching for new options. In the future the environmental impact of materials will become smaller. Therefore it is expected that when structurally using the most environment-friendly product, this can reduce the MPG-value by 0,18. Of course this also overlaps with the previous mentioned strategies(Lente-Akkoord 2.0, 2023).

Building ‘slender’ can be a way of decreasing the amount of materials used in a building. By applying thinner floors and walls, as long as they stay within the required measurements, the MPG can be improved. However, building ‘slender’ influences the energy performance(W/E adviseurs, 2023). Therefore the energy concept of the building should be kept in mind. The energy concept determines the operation of the building regarding energy. One building is built with a lot more materials than another, but is more energy efficient. For example, a passive building with a lot of insulation in the facades and triple glass windows will have a lower energy demand than an active climate scheme with solar panels on the roof and thin facades. Therefore it is best to find a balance between these two, since these materials are influential for both the energy performance and environmental performance of the building.

Experts already expect that decreasing the amount of insulation, using thinner glass and taking aways solar panels are the first measures that will be taken when the required MPG-value becomes lower. Building ‘slender’ can still decrease the MPG-value by up to 0,09 €/m2.year(Lente-Akkoord, 2023). Moreover, if less materials are used which is beneficial for the MPG, there can also be saved a lot of costs(Arnoldussen et al., 2023).

Not only the choice and use of materials are important when trying to reduce the environmental impact on a building. A strategy that may have less impact but is worth to mention is the design of it, since this determines the amount of materials needed. For that reason certain choices regarding the shape of the building can influence the MPG-value. For example high ceilings will increase the amount of needed materials while the total Gross Floor Area stays the same. Furthermore the façade can be influential, since a simple straight façade contains less materials than a façade with offsets. The same applies for the roof; a simple flat roof will be more favorable for the MPG-value than a gable roof(Arnoldussen et al., 2023). A material efficient design can save up to 0,03 €/m2.year(Lente-Akkoord 2.0, 2023).

As mentioned before the MPG-value is calculated by dividing the total prevention costs by the total GFA and by the lifespan of the building. In previous strategies the (relative) amount of GFA was tried to be increased, which would lower the MPG-value. However increasing the lifespan of the building will also give a lower MPG-value. The current calculation method is based on a standard lifespan of 75 years. This can be extended, but this will require more maintenance and some parts will possibly have to be replaced at some point. It is important to mention that an extended lifespan only affects the environmental impact of the parts that have a longer technical lifespan than the lifespan of the building itself, in other words; the parts that have to be replaced due to a longer lifespan do not contribute to the improvement of the MPG-value *(Rapport Richtlijn specifieke gebouwlevensduur*, 2020). However they do not worsen it either. Although some installations or individual parts may not be able to hold up a longer lifespan than 75 years, the constructive parts are rarely a problem. If the lifespan is expended with a realistic amount of years, this can cause a decrease in the MPG-value of 0.08 €/m2.year(Lente-Akkoord 2.0, 2023).

Last but not least thinking about the future of the building can improve the environmental performance of a building. The best way to do this is building demountable, so the used parts can easily be reused after its lifespan. This strategy can currently save up to approximately 0.02 €/m2.year. However the influence of this strategy is not fully recognized by the current calculation method(Lente-Akkoord 2.0, 2023).

5.3 Consequences

Implementing these strategies to decrease the environmental impact of a building will have consequences, for example financial ones. Strategies containing the use of different materials or more sustainable materials than in the current traditional ways will have consequences. It is expected to cause a raise in building costs, which in most cases only require some one-time costs for changes in the design. Industrial construction companies will have more difficulties with adjusting their design, since they use more standardized designs for their projects. The MPG-value of 0.5 is expected to be doable in most cases, but if this required value would become lower in the future, this will give big difficulties for them(Arnoldussen et al., 2023).

Not every strategy will have a negative impact on the costs. As already mentioned before, building 'slender' means a decrease in the amount of used materials, which will decrease the costs. However, the building still needs to meet the requirements regarding energy performance so when for example there is used less insulation material, this must be compensated by using insulation material with a higher insulation value. In the end on macro-level there will be no big changes in costs, since the biggest part of the newly build real estate will be able to meet the MPG-requirement relatively easy. Besides, the inflation and interest is estimated to be higher than the increase of construction costs for improving the sustainability and decreasing the environmental impact. Besides building 'slender' there is another strategy that can save costs; using recycled materials is less expensive than using new materials. Their value is determined based on their condition, which is the best if they were formerly used in a demountable building.

Besides the financial consequences these strategies influence other aspects too. The choice for certain materials can also affect the indoor environment of a building. In the case of using bio-based materials this influence can even be positive for this indoor environment, since for example bio-based natural fibre materials such as cork, cotton, wood fibre and hemp have a moisture-buffering capacity. According to research of the Technical University of Istanbul wood fibre can have a lambda-value between 0.048 and 0.055 W/mK, which is not that much higher than commonly used insulation materials like 'steenwol'(0.038 W/mK), 'glaswol'(0.039 W/mK) and EPS(0.035 W/mK). This means that wood fibre only has to be used in a bit bigger thickness than when one of the previously-mentioned materials. This could be favorable for the MPG(Çetiner & Shea, 2018. Other innovative ideas like insulation material using water-based resin from wastes such wood shavings, wheat straws and goose down could bring the large amount of waste into the economy. Since the amount of waste is also brought down, this would have a positive effect on the environment, however it is assumable this is not implemented in the current MPG-calculation method yet.

5.4 Shortcomings in MPG calculation method

The current calculation method that is used to determine the environmental impact of a building lacks on multiple aspects. Not all strategies to improve the MPG that are mentioned above are sufficiently taken into account in the calculation. To acknowledge the real effect of these measures, the calculation method should be restructured. This is a known problem and it is likely that it will happen in the future(W/E adviseurs, 2023).

One of the main lacks in the current calculation method is the missing of a lot of possible materials. For example the use of recycled constructive parts is not fully possible to select, although this can make a big difference in the MPG. Materials that are recycled are being processed as new materials, which gives a wrong image of course. This also applies to bio-based products. In some cases the environmental impact of bio-based materials are scoring even worse than normal materials(W/E adviseurs, 2023).

Another problem within the current calculation method regards the energy concept of the building. At this moment there is made no division between different ways of producing energy. Whether the energy is renewable or not, they get the same score in calculating the MPG, although this certainly has an influence(W/E adviseurs, 2023).

Furthermore the lifespan of products in the building are underestimated regarding their environmental impact. In the current method it is not possible to adjust the lifespan of installations for example. If there are taken certain measures to extend their lifespan, it is not possible yet to implement this is the calculation, so this positive effect on the MPG is not taken into account. For that reason extending the lifespan of products in the building can only lead to a decrease of 0.02 €/m2.year in the MPG. If the calculation method would be more detailed, this could be a lot more(Lente-Akkoord 2.0, 2023).

When using recycled materials in a building, the environmental impact becomes smaller, since no new materials have to be made. However this is also a strategy of which the influence on the environmental impact is not fully recognized within the calculation method. It is expected that this will change since more and more recycled products are added to the NMD. If there are used recycled products wherever this is possible, this could cause a decrease in MPG of 0.1 €/m2.year. Besides using recycled materials, building demountable is also not recognized within the calculation method. It is hardly taken into account in the NMD. This is because of the fact that especially connecting parts are recycled, which is difficult to implement(Lente-Akkoord 2.0, 2023).

However not all strategies are undervalued, for example the strategy of using a slender construction with cross laminated timber and a wooden façade. This can actually be a huge influence on the MPG-value which is also processed through the calculation method.

In the upcoming years the MPG-calculation method is expected to be improved and expanded, so within a few years it can function as the main sustainability-indicator in the Netherlands. This will be done by expanding the NMD, which is the database containing 'product cards' of all type of materials and products that are used within the construction sector in the Netherlands. This 'product card' is in fact an Environmental Product Declaration which was explained in paragraph 3.1. A material can only influence the MPG if it has its own EPD in the NMD, but this is not always the case. Since this system is only used in the Netherlands big international manufactures will often not make the effort to do an LCA since the Netherlands is just a small part of their sales market.

Registering materials and products is necessary, since the calculation method will appreciate the different strategies more accurately, since some strategies are affecting the environmental impact more than is noticeable in the MPG-calculation.
Besides improving the calculation method, environmental performance and energy performance of buildings could also be combined into one integral indicator: the MPEG. This indicator is being worked on at the moment and also includes the environmental impact as a consequence of energy use during the user-phase of a building. On European scale there is a plan for a integral indicator as well: the EPBD IV(Energy Performance of Buildings Directive IV). This contains guidelines for all European Union countries that have to be translated to all national regulations(*Richtlijnen energie - overzicht EU-beleid Nederlandse bouw en vastgoedsector*, z.d.).

5.5 Difficulties for apartment buildings

This research is focused on apartment buildings for a reason. To meet the new required MPG-value of 0.5 from 2025 on, new ways of building are needed to decrease the environmental impact. This is expected to be doable, but it will be more difficult for certain types of buildings than others.

The MPG is a scale that is measured per square meter GFA, which stands for Gross Floor Area(Arnoldussen et al., 2023). The GFA is the total floor area of all floors in square meters including the exterior walls and technical rooms. This means that in certain types of buildings the floor area compared to the construction, walls and installations is smaller than in other types of buildings. This causes an increase in the MPG-value. This is especially the case in small houses, like tiny houses or apartment buildings. With the current housing shortage and the need for building a big amount of houses in a short period of time, these are just the types of houses that are necessary to build.

LBP/SIGHT and DGMR showed the relation between the type of building and the MPG-value with some reference projects, that are shown in figure 4 below. By creating this set of reference projects they tried to give the government a good overview of the effects of tightening the MPG-requirements.

Type of building	**GFA**	**Minimum MPG-value (€/m2 . jaar)**	**Maximum MPG-value (€/m2 . jaar)**
Terraced house	87	0,672	0.837
	142	0,461	0.521
Corner house	173	0,378	0,421
Detached house	206	0,459	0,669
	253	0,429	0.563
Appartment-building 33 units	80	0.574	0,630
Appartment-building 45 units	100	0,655	0,725
Appartment-building 133 units	92	0,636	0,702
Appartment-building 222 units	55	0.861	0,963
Appartment-building 604 units	43	0,940	1.064

Figure 4: MPG-values reference projects (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2023)

In the figure above it is shown that the MPG-values of the apartment buildings is clearly higher than the MPG-values of the terraced houses, corner house and detached houses. There is also a visible connection between the GFA and the MPG: the lower the GFA of the apartment, the higher the MPG-value. The amount of units in the building is also influencing this.

The fact that relatively small houses have a higher MPG-value has multiple reasons. First of all as mentioned before, these houses have relatively much materials compared to the GFA. In an apartment building more floor area is taken by interior walls for example. Furthermore an apartment building with small houses contains relatively more installations than a single-family house, since it also has more inhabitants per square meter.

Furthermore apartment building are usually higher than normal single-family houses, which also means there are more rules to adhere to, especially regarding the construction. These rules result in heavier constructions and therefore more materials. A high and thin tower will need more materials than a big and wide but low building with the same GFA(Arnoldussen et al., 2023).
An aspect that has less influence on the MPG is the floor height. The bigger the floor height, the more façade is needed per square meter. However an increase of 10% in height causes an increase in MPG of only 2% or 3%(Rekenen aan milieuprestatie, 2020).
Besides the height of the floors the amount of floors is influential for the environmental impact. Communal facilities like an entry, hallways or the foundation of a building contains materials that will be divided among a certain amount of houses in the building. The more floors a building consists of, the more dwellings these communal materials can be divided among. It should be taken into account that a high building needs a heavier construction which also contains more material.

5.6 Other difficulties

Besides the size of the dwellings, which is small in case of the apartment buildings, there are some other factors that affect the MPG in a negative way. These factors make it difficult to meet the MPG-requirement too.

The geographical location of a project determines some important elements to take into account. In some areas in the Netherlands the soil contains peat, which cause a need for a foundation on piles, no matter the size and height of the building. This means there is more material needed anyways.

5.7 Current-supply side

The MPG is included within the 'bouwbesluit' since 2013. Since then companies are innovating to meet the requirements for buildings. Most of them are focusing on certain individual strategies to become specialized in. Since the different strategies can be combined but do not all deliver the maximum outcome, these companies try to find the combination that gives the best result. However there is not a lot of information available yet about the best way to find this combination.

5.8 Missing knowledge

Based on the main findings of the literature research there can be concluded that there are possible strategies available for apartment buildings to still improve the MPG a lot. However it is difficult to measure if these strategies will lead to an MPG-value lower than 0,5. Can the mix of these strategies really cause such an improvement?

Moreover there is less knowledge available about the consequences of these strategies for the feasibility of the developer. A developer wants to be able to come up with a feasible business plan. Will the use of these strategies lead to higher costs? And what impact will it have on the living environment, which is something that the future residents care about?

6. Hypothesis

Before doing the actual research there can be set up a hypothesis. Based on available information and expectations, parts of the outcomes could be predicted, but not proven yet. Earlier in this report the conceptual model showed the different variables involved in this research. The model also shows the impact of one variable on the other and certain relationships between them.

6.1 Expected outcome

In figure 5 below the conceptual model is shown again, but this time the expectation of every variable is shown. The variables that are expected to be positively influenced by the strategies to reduce environmental for the regarding stakeholder(investor & end-user) are green, the ones that are negatively influenced are red.

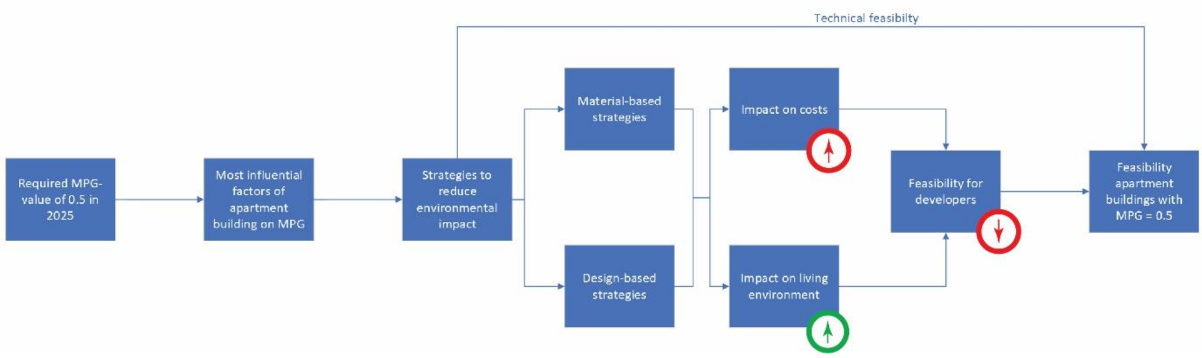

Figure 5: Conceptual framework with expectations per variable (Own work, 2024)

As can be seen on the top-half of the figure, which is the supply side of the apartments, the strategies to reduce environmental impact are expected to be influencing the developer's feasibility in a negative way. Although some of the strategies are lowering the **costs**(see paragraph 3.3), in the end they are expected to be higher while taking these measures to lower the environmental impact of the building. This will mostly be due to more expensive sustainable materials(for example bio-based materials)or materials that are produced in a more sustainable but complicated way. Looking at the design-based strategies the change in design will also increase the costs, especially in the beginning. If the costs increase, it will be more difficult for developers to find investors.

An increase in costs will cause a negative impact on the feasibility for the developer since this will make it more difficult to come up with a feasible plan. A rise in costs will force the developer to increase the future rent price or sale price and especially with a required amount of affordable housing he has to build, this makes it less feasible.

If we look at the end-user's side of the figure, we can see an expected positive effect regarding the impact of the strategies on the **living environment**. This expectation is especially based on the strategy to use more bio-based materials. Some of them are expected to have a positive impact on the resident's health. For example the use of natural fibre materials such as cork, cotton, wood fibre and hemp have a moisture-buffering capacity. Since this improves the quality of the building this can lead to a higher rent price or sale price. However it could be questioned whether this equals the rise in costs.

7. Validating literature findings: Explorative interviews & additional literature

In chapter 6 the main findings of a critical literature review were discussed. Topics like the definition of the MPG, ways to improve the MPG-value of a building and its consequences were discussed to contribute to answer the research questions. The world of construction contains constantly changing trends. To get the most recent and useful insights into the current status of the MPG in the Dutch world of construction, three interviews were done.

First of all an interview was conducted Circularity & Sustainability-manager of a Dutch company focused on building with wood. This company is focused on creating a positive impact on the planet by building with biobased materials. Their vision of minimalizing the negative impact on the environment and building with wood fits well with this research, which was a good reason to talk to this.

The second person that was interviewed works as a senior consultant. This person focuses on the implementation of sustainability in the world of construction, for example by thinking about how to regulate this, especially regarding materials and circularity.

Last but not least there was spoken to a plan developer at a Dutch construction company. This person is specialist in their portfolio of concept housing, both apartments and single-family homes which is meant to create affordable housing in a fast way.

7.1 The 'Milieu Prestatie Gebouwen'

In chapter 6 the definition of the 'Milieu Prestatie Gebouwen' according to various literature sources was discussed. It was called '*the most important instrument to decrease the environmental impact of newly build housing and offices.*' (W/E adviseurs, 2023). Nowadays the required MPG-value is 0.8 €/m2.year, which is a requirement that has to be met to receive a permit to build. In practice this results in a fast and carelessly made calculation, lacking a lot of factors of the building. Since nobody is checking the correctness of the calculation, this does not matter. In some cases even calculations of completely different buildings with low MPG-values are submitted(Interviewee 2, 2024).
In December 2022 the intention was expressed to lower the maximum MPG-value to 0.5 on the 1st of January 2025(Arnoldussen et al., 2023). In December 2023 this change was delayed with 6 months to the 1st of July 2025, because processing the future changes will take more time than expected(Levels-Vermeer, 2023). Besides Minister Hugo de Jonge wants companies in the construction sector to be able to prepare for these changes(Van der Zee, 2024) In the meantime the amount of environmental effects, that were discussed in chapter 6.1 of this report, is increased from 11 to 19. This means the amount of prevention costs which determines the MPG-value will be higher than before. For this reason a maximum value of 0.5 €/m2.y will not be the requirement anymore.

The so-called A2-change will not lower the required MPG-value for residential buildings from 0.8 to 0.5, but it will go up to 1.0(Levels-Vermeer, 2023). This value is the result of the estimation that the added environmental effects on average will cause a double of the prevention costs.

However research showed that adding the 8 extra environmental impacts will cause in increase in the gap between single-family-homes and multi-family-homes, which makes it impossible to set the same requirements for both. For that reason there will be made exceptions for stacked residential buildings, so for example apartment buildings. These types of buildings will not have to meet a required MPG-value of 1.0, but a value of 1.2(Levels-Vermeer, 2023). It is expected that this required value will be correlated with the size of the apartments, so it could still deviate from 1.2 in the end(Interviewee 2, 2024).

Figure 6 below shows the MPG-scores of various reference projects assuming the initial plan to include 11 environmental effects. On the X-axis 25 different types of buildings are showed. Type 11-25 concern apartment buildings, that are described in the table in figure 8. Since every reference project is calculated with a variety of energetic packages, they contain different versions, that are showed with different colors of dots.

Figure 6 shows almost all reference projects of apartment buildings do not meet the required MPG-value of 0.5. The best-scoring types of apartment buildings are type 13(33 medium-sized apartment buildings traditionally built with collective spaces) and type 24(374 XL dwellings with collective spaces).

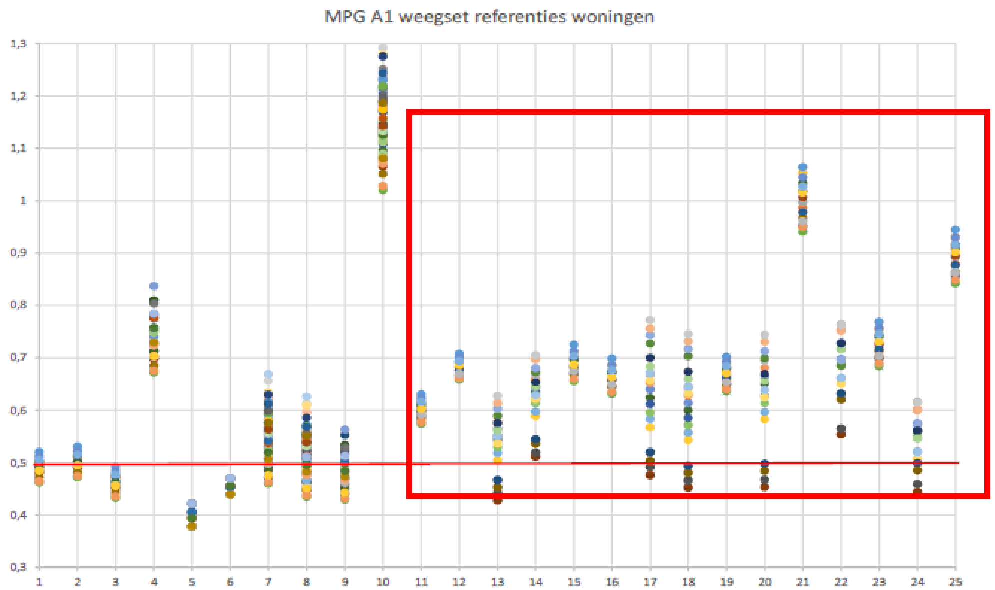

Figure 6: MPG-values reference projects assuming a future required MPG-value for residential building of 0.5 (Levels-Vermeer, 2023).

Not all versions of these references have an MPG-value below 0.5. For type 13 and 24 the worst scoring versions have an MPG-value of 0,63 €/m2.y. The biggest part of the versions still do not meet the 0.5. However their relatively low MPG-value is expected to be thanks to their collective space, which decrease the amount of needed installations for example.

The graph in figure 6 shows the need to construct and design apartment buildings differently in the future to be able to meet the new requirements. Another remarkable result is the difference between traditionally built projects and projects built with CLT. Although last mentioned would be expected to have a lower MPG-value, the traditionally built one scores better according to this study. This is visible at type 11 vs type 12 and at type 15 vs type 16.

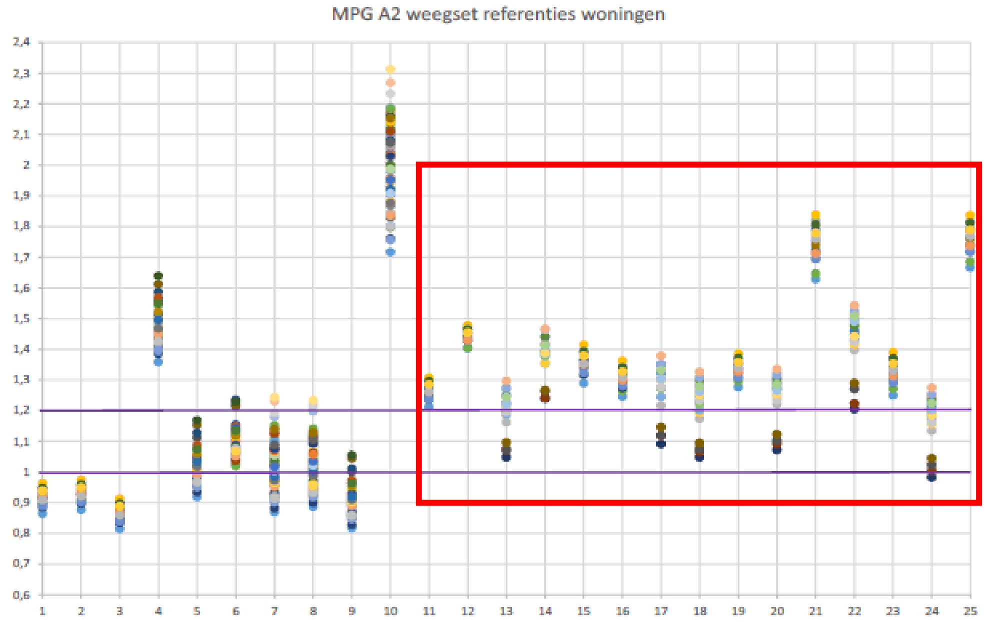

Figure 7: MPG-values reference projects assuming a future required MPG-value for residential building of 1.0 and a future required MPG-value for apartment buildings of 1.2(Levels-Vermeer, 2023).

Figure 7 above shows the MPG-values of the same reference projects as showed in figure 6, but the purple horizontal line now indicates a required MPG-value of 1.0 for residential buildings and 1.2 for apartment buildings. Clearly the projects within the red frame are a lot closer to this value and some of them even already meet it. For type 13, 17, 18, 29 and 24 the best versions regarding energetic packages have an MPG-value lower than 0.5. The only types that are still far away from meeting the requirements are type 21 and 25. Type 21 is an apartment building with 604 XL dwellings, which already scores a lot better when having collective spaces(type 22) and type 25 concerns an apartment building with 222 large-sized dwellings.

The correction that this future requirement contains will make it more realistic for real estate companies to meet the expectations regarding environmental impact. Although the buildings with small apartments will still have some difficulties, the bigger apartments will be able to meet these values(Interviewee 2, 2024). Since this research started in October 2023, before the addition of 8 extra environmental effects which increases the required MPG-value, this research will still be based on a required MPG-value of 0.5 €/m2.y. However the MPG-calculation maintains a means to show that there has been thought about how the building was built. In the end building in a sustainable way is the tool that should be used(Interviewee 1, 2024). The conclusion of this research will still be the same, regardless of an MPG-value of 0.5 or 1.2.

11	Apartment building with 33 medium-sized dwellings traditionally built
12	Apartment building with 33 medium-sized dwellings built with CLT
13	Apartment building with 33 medium-sized dwellings traditionally built - collective
14	Apartment building with 33 medium-sized dwellings built with CLT - collective
15	Apartment building with 45 medium-sized dwellings traditionally built
16	Apartment building with 45 medium-sized dwellings built with tunnel construction
17	Apartment building with 45 medium-sized traditionally built - collective
18	Apartment building with 45 medium-sized dwellings built with tunnel construction - collective
19	Apartment building with 133 large-sized dwellings
20	Apartment building with 133 large-sized dwellings - collective
21	Apartment building with 604 XL-studios
22	Apartment building with 604 XL-studios - collective
23	Apartment building with 374 XL-dwellings
24	Apartment building with 374 XL-dwellings - collective
25	Apartment building with 222 large-sized dwellings

Figure 8: Reference projects regarding apartment buildings(Levels-Vermeer, 2023).

7.2 Biobased materials

In paragraph 6.2 of this report different ways to improve the MPG of a building according to literature were described. One of the most important and effective ones was the use of biobased materials. According to the LenteAkkoord 2.0(2023) this could lead to significant decreases of up to 0,18 €/m2.y. in the MPG-value. An example of biobased materials is wood, which will be discussed more in detail in the next paragraph. The interviews gave important insights in the advantages of using biobased materials.

When using renewable materials in a building this is very favorable for its MPG-value. Materials like recycled wood as mentioned in paragraph 6.2 have a much more favorable environmental impact compared to glass wool for example. This is visible when looking at the MKI's (the number on the left) in figure 9 below.

☐ 0,66 Cat. 3 Isolatielagen, Glaswol MWA 2012; platen;

☐ 0,16 Cat. 1 PAVATEX PAVATHERM houtvezelisolatiemateriale 110 kgm3 buitenwanden

Figure 9: Comparison of MKI's per m2 of glass wool and recycled wood as insulation materials(GPR materiaal, 2024.)

When looking at the difference between the MKI's of these materials there should be taken into account that the energy performance differ, which means the required amount to reach a certain energy performance differs too. Glass wool has an lambda-value of 0,031 W/mK(Nederland isoleert, n.d.), while the recycled wood-material has a lambda-value of 0,038 W/mK(infodubo, 2020).

Most people consider the use of biobased materials as more expensive than traditional materials. However this is not because of the materials themselves, but because of the research(Interviewee 1, 2024). '*We are used to build with concrete and steel, so we already have done a lot of research to these materials regarding fire safety, stability and other aspects. We do not have to do all of that anymore, since we already have all data and characteristics*.' (Interviewee 1, 2024). To use new biobased materials for buildings these researches have to be done again, which will cost money and time, but as soon as these data comes available and the market for these materials grows, biobased materials are expected to cost approximately the same as traditional materials(Interviewee 1, 2024). This is just a 'financial threshold' we have to step over.

Another reason for this 'financial threshold' is the fact that manufacturers will have to pass the costs of their increasing costs for becoming more sustainable in the price for the client. For example Tata Steel recently came up with a big plan to produce their product in a more sustainable way, which could lead to a lower MPG-value for the buildings it is used for too. Especially taking the future tightening of the required MPG-value into account, this is a favorable step for them, but they can only execute this plan if these extra costs are paid by the client(Interviewee 1, 2024).

Interviewee 1 personally predicts that in a further future biobased materials could even become cheaper than traditional materials, because of a possible future taxes for CO2-intensive materials. It is expected that at some point the use of these materials will be destimulated by the government. Furthermore he expects that as soon as the supply side of biobased materials grows, its prices will decrease.

7.3 Wood vs concrete

As mentioned before one of the biobased materials that could be most influential for the MPG-value is wood. Later in this report different case studies will be done including both projects built with wood and projects built with concrete. This will show the size of this difference.

According to the Lente-Akkoord 2.0(2023) the use of HSB(Timber Frame Construction) could cause a decrease of +-0,07 €/m2.year in the MPG-value, where the use of CLT(Cross Laminated Timber) could even take away 0,15 €/m2.year. Nevertheless the literature also indicated that the environmental advantage of wood is not fully included in the MPG-value, which makes it less attractive to build with wood. The underscoring of biobased materials was discussed earlier in paragraph 6.4 too. Interviewee 1: 'The use of wood is underscored because it is assumed that it is being burned after 75 years, which causes CO2-emissions. However, wood also stores CO2 during its lifecycle and according to the European legislation this effect is only taken into account in the MPG if it has a lifecycle of 100+ years. Since the Dutch legislation uses a standard lifecycle of 75 years for wood, this positive effect is not included(Interviewee 1, 2024). Interviewee 2(2024) points out this is a big point of discussion: '*The storage of CO2 happens in phase A, the production phase. This causes the so-called minus-one which stands for the absorption of the CO2. However in the end the CO2 will come out again during phase B or C, where it will be burned or composted, even if it is recycled. This causes the plus-1. In the end the whole lifecycle has a result of zero.*'

So CO2 is only stored temporary. Nevertheless the current climate goals entails the reduction of CO2 within 10-15 years, so the temporary storage of CO2 could still be helpful(Interviewee 2, 2024). For this reason building with wood could have a positive environmental effect on the short-term which then also should be included in the MPG-calculation.

When looking purely to the material itself, wood does have a better MKI than concrete nowadays, since the implementation of the effect of wood in the calculation method has been improved(Interviewee 1, 2024). In figure 10 below the CLT Stora Enso floor is compared to the concrete 'kanaalplaatvloer' with the best MKI. The CLT floor has a significantly lower MKI measured per square meter, which shows the advantage of wood regarding floors.

- [ ] 0,35 Cat. 1 CLT by Stora Enso Vloeren, constructief
- [ ] 2,66 Cat. 1 Bruil prefab kanaalplaatvloer S200

Figure 10: Comparison of MKI's per m2 of CLT floors and concrete kanaalplaat-floors(GPR materiaal, 2024)

When looking at the application of wood in the façade, wood is also scoring better. In figure 11 the MKI of a HSB exterior non-constructive wall is shown. Below a traditional exterior wall(excluding insulation and finishing) is shown, which has a MKI of almost 1,7 times more than the HSB wall.

- [ ] 1,48 Cat. 3 Systeemwanden, HSB element; Europees naaldhouten multiplex en gipsplaat; duurzame bosbouw
- [ ] 2,49 Cat. 3 Spouwmuren binnenblad, Leemsteenmetselwerk

Figure 11: Comparison of MKI's per m2 of HSB exterior wall and a traditional masonry(GPR materiaal, 2024)

These MKI's that are used in the GPR software to calculate the MPG-value show that wood is already scoring better nowadays, but it also brings other advantages with it. The Dutch company De Nijs developed a project which they worked out in both wood and concrete to see the differences regarding design, time, costs, logistics and sustainability. They called it 'the Wooden Lion vs the Concrete Lion'(In Dutch 'De Houten leeuw vs de Betonnen leeuw)(De Nijs et.al., 2023).

First the wooden version(figure 12) was worked out, containing 53 compact studios. The construction consisted of CLT floors and walls and there was a wooden gallery construction and stairs made of Azobe wood. To then create the concrete version, the construction of CLT was converted into concrete and steel. A traditional way of building was applied by using concrete walls and floors and the gallery construction was made of steel and prefab-concrete, including prefabricated stairs. These construction are visualized in figure 12 and figure 13.

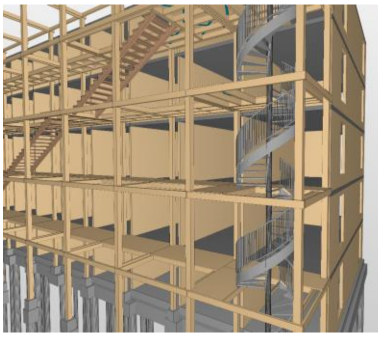

Figure 12: Wooden Lion(De Nijs et. al., 2023)

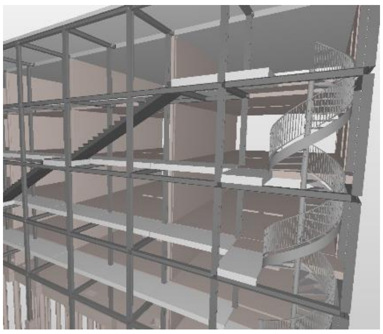

Figure 13: Concrete Lion(De Nijs et. al., 2023)

One of the differences between these two versions concerns the foundation. The wooden version required 15% less foundation poles than the concrete version because of the lighter weight(De Nijs et.al., 2023).
Nevertheless when looking at the logistics the concrete version came out more favorable, since the total distance between the construction site and the material-factory was two times higher in the case of wood, since it was mostly from Austria. This caused more CO2-emissions, NOx-emissions and PM-emissions, which negatively affected the MPG-value.

In the end the Wooden Lion has a total MPG of 0,69 €/m2.y. when the storage of CO2 is included. If it is not, the MPG would be 0,79 €/m2.y. The Concrete Lion has a total MPG-value of 0.82 €/m2.y., so the difference between these two is only 0,03 since the storage of CO2 is not included in the Netherlands. Figure 14 shows that the difference in material-based CO2-emissions is much bigger than between the total MPG-values. This means that the other phases than the production phase compensate this.

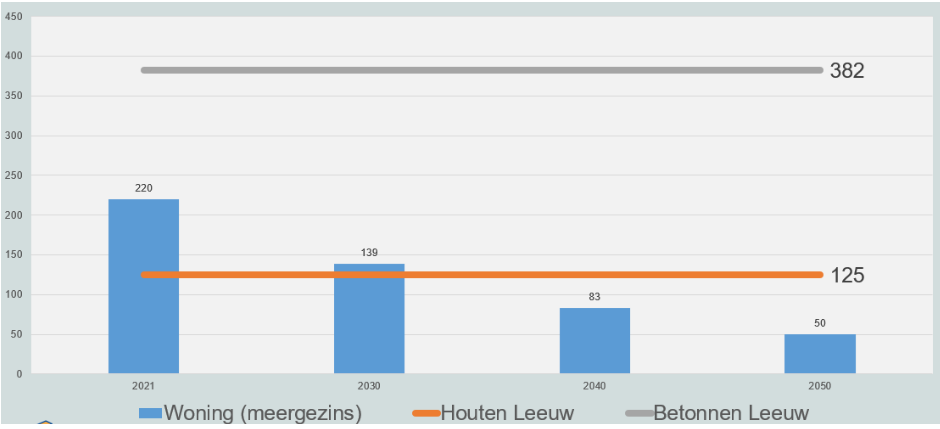

Figure 14: Material-based CO2-emmissions in kg CO2-eq / m2 BVO(De Nijs et. al., 2023)

Besides the use of materials there was also looked at the use of biobased materials and the possibility of reuse and recycling. 20% Of the materials used in the Wooden Lion was biobased, which was only 2% in the case of the Concrete Lion. Furthermore 63% of the Wooden Lion is expected to be demountable versus only 19% of the Concrete Lion. When looking at the possibility of recycling the Concrete Lion scores better: 83% vs 51%. Last but not least it is expected that only 1% of the concrete version can be reused, while this is 17% for the wooden one(De Nijs et. al., 2023).

The total difference in MPG between the Wooden Lion and the Concrete Lion is 18%. However De Nijs also mentioned that the Wooden Lion was not designed to have an MPG-value as low as possible. The foundation could have been lighter and a big improvement regarding the installations would have been possible. The difference between the two versions could have been even higher than 18% in favor of the Wooden Lion(De Nijs et. al., 2023).
Other differences are the slightly higher costs for the Wooden Lion(4,2% higher), 5,81% less m2 of GFA due to thicker walls in the case of wood and a 2-months shorter construction time

The implementation of wooden elements in the MPG-calculation method is becoming better and already scores a bit better than concrete. The use of wood also makes a lighter foundation possible which decreases the environmental impact of the building. It can score even better if the storage of CO2 would be included, however this topic is still of discussion.
Other elements that are affected by the use of wood but not discussed yet are the installations. This will be discussed in paragraph 8.4.

7.4 Environmental performance & energy performance

In chapter 6.2 the strategy of 'building slender' was discussed, where the use of thinner walls and floors would decrease the amount of materials needed which would lead to a lower MPG-value. It also stated that while doing so, the energy concept should be kept in mind since thinner walls and floors could influence the energy performance in a negative way(W/E adviseurs, 2023).

The energy performance and the environmental performance are constantly clashing. For the first one as much materials as possible should be used, but for the second one as little as possible. For example a thick layer of insulation will keep more heat inside which can decrease the heat demand, but in the meantime the production and possible destruction of the material will increase the environmental impact(Interviewee 1, 2024).

Elements that are even more influential than the amount of insulation, are the installations. These are often favorable for the energy performance but they can have a huge negative influence on the environmental impact. This will be visible in the case studies, that will be described in chapter 9.

'*An often-occurring problem nowadays is that a beautiful building is built, including a lot of solar panels. Well, then you will fail on your MPG*.'(Interviewee 2, 2024). To meet both the future MPG-requirements and the BENG-requirements it seems to be necessary to keep both in mind from the beginning of the design process of the building. It will not be possible anymore to take a look at the MPG only when the design is already finished.

In paragraph 8.3 several advantages of wood regarding the MPG were mentioned. However wood also has negative consequences, for example for the energy concept. Nowadays a building has to meet the NTH8800-rules, that are about the energy performance of newly built buildings. This contains requirements about the heat-and-cold demand, primary use of energy, renewable energy and the so-called 'TOjuli-requirement'. This TOjuli-requirement is created to guarantee a reasonable indoor climate during the summer and is therefore measured in July (Halfens, 2021).

The TOjuli is being measured by dividing the heat surplus or cold demand by the thermal resistance of the façade. The result should be equal or lower to 1.2 to meet the TOjuli rule(Halfens, 2021). The higher the thermal resistance of the façade, the lower this number is. To get a high thermal resistance of the façade it is favorable to decrease the amount of glass and increase the amount of mass and weight(Interviewee 1, 2024). Since the weight of concrete is +-4,5 times the weight of wood, wood lets more heat through than concrete, which means this has to be compensated by adding a thicker layer of insulation to the façade. Besides a wooden building will require an active cooling system more often than a building of concrete, since it should be indicated that the building is capable of maintaining a reasonable temperature inside(Interviewee 1, 2024). In the winter there will be heat demand, but the lower the heat demand, the smaller the required heating boiler(Interviewee 2, 2024). For this reason a building built with wood is expected to have a higher MPG-value for installations than a building built with concrete.

'*It is a bit of a 'material vs building as a whole'- comparison. If you purely look at the material concrete definitely scores worse than wood, but when looking at the building as a whole they will probably be almost equal. It is a bit like comparing apples and oranges.*' (Interviewee 1, 2024)

7.5 Reusing, recycling and lifespan

Among the strategies mentioned in paragraph 6.2 the terms 'reusing' and 'recycling' were discussed. Both could decrease the MPG-value and sound similar, but they are not the same. When an item is reused, it is repurposed for extended use. When an item is recycled its materials are reprocessed so it can be used elsewhere(Wilkinson, 2024).

Reusing materials can have positive effects on the environmental impact of a building, since the materials does not have to be produced again. However in the past this positive effect was not represented sufficiently in the MPG-calculation method. Little by little this is being improved. In the figure below is shown the ability to check a box on the right, which indicates a reused material.

Figure 15: Comparison between new glass and reused glass(GPR materiaal, 2024)

In figure 15 the MPG-value of a new material and a reused material are compared. Triple glazing was randomly picked as a material that has a relatively high MPG-value and the difference is clearly visible. The reused version of the glass has and MPG that is 0,016 €/m2.y. lower than the new version, which is a decrease of more than 25%. If more materials are reused in the building this could help a lot reaching an MPG-value of 0.5,

If it is demonstrable that a certain material is reused you are allowed to cross out the whole production phase of the materials MPG-value(Interviewee 1, 2024). Since this phase usually has the biggest share of the total MPG-value, this can be quite favorable.

Not every element of a building is reusable. Sometimes it is at the end of its lifecycle, but the materials can be reprocessed(Wilkinson, 2024). In those cases materials can be recycled. An example mentioned by Interviewee 1(2024) is the Freeman Concrete manufactured by New Horizon. This product partly exists of new concrete and partly of recycled concrete, which is therefore also called a hybrid material. In case of an innovative solution like this it is important for the manufacturer to register this material in the NMD, otherwise it cannot be represented in the MPG and it does not provide any benefit.

Reusing elements from former buildings is beneficial, however the former building does not get a lot benefit out of it. This is because of the fact that is difficult to prove at forehand an element will be reused after its lifespan. Interviewee 1(2024): '*While you produce a certain material for the first time, you should be able to prove it will be reused 1-on-1 at the end of its lifespan, which is difficult since we are talking about a period of 75 to 100 years. Who is going to ensure there will still be demand for this material in 75 years?*'.

In paragraph 6.2 the strategy to expand the lifespan to improve the MPG-value was discussed. Since the MPG-value is calculated by divided the prevention costs by the lifespan in years, this would be beneficial. However is this advantage fully included within the MPG-calculation tool?

To test this effect a random MPG-calculation was picked, shown in figure 16 below. This project has a total MKI of €274.381,922 and a total GFA of 5759,83 m2. Like most of the projects in the Netherlands a lifespan of 75 years is assumed which leads to an MPG-value of 0,635 €/m2.year(274.381,922/(5759,83 x 75)). If the lifespan was 100 years instead of 75 and the MKI was assumed to remain the same, this calculation should result in a value of 0,476 €/m2.year(274.381,922/(5759,83 x 100)). Nevertheless, a bigger lifespan influences the MKI too since the MPG-value of the use phase increases. Figure 16 and 17 below show the difference between these MKI's.

MPG Berekend per m2 BVO, per jaar	0,635
A. Productiefase	0,345
A. Constructiefase	0,015
B. Gebruiksfase	0,345
C. Afdankfase	-0,009
D. Buiten gebouwlevensloop	-0,061

MKI Berekend over de totale BVO en levensduur	274.381,922
A. Productiefase	148.999,893
A. Constructiefase	6.299,853
B. Gebruiksfase	149.011,510
C. Afdankfase	-3.782,414
D. Buiten gebouwlevensloop	-26.146,921

Figure 16: MPG-value & MKI of randomly picked project assuming a lifespan of 75 years(GPR materiaal, 2024)

MPG Berekend per m2 BVO, per jaar	0,610
A. Productiefase	0,259
A. Constructiefase	0,011
B. Gebruiksfase	0,392
C. Afdankfase	-0,007
D. Buiten gebouwlevensloop	-0,045

MKI Berekend over de totale BVO en levensduur	351.172,929
A. Productiefase	148.999,893
A. Constructiefase	6.299,853
B. Gebruiksfase	225.802,517
C. Afdankfase	-3.782,414
D. Buiten gebouwlevensloop	-26.146,921

Figure 17: MPG-value & MKI of randomly picked project assuming a lifespan of 100 years(GPR materiaal, 2024)

The figures above show that the MKI of the use phase is big, which decreases the impact of expanding the lifespan significantly. The bigger MKI is caused by the fact that parts needs to be replace or repaired more often. In the end it is still an advantage to expand it, but the effect is less than expected.

7.6 Form factors

In chapter 6.5 of this report it was explained why the new future required MPG-value of 0.5 will especially cause difficulties for apartment buildings. The relatively high amount of interior walls and installations compared to the total GFA increases the MPG-value. Besides, apartment buildings often have more building layers than normal houses, which make them require a heavier foundation. Furthermore, the floor height was discussed since a bigger floor height increases the relative amount of façade needed.

Among developers and contractors it is recognized to be really difficult to meet an MPG-value of 0.5 €/m2.y. for apartment buildings, especially for small apartments(Interviewee 2, 2024). *'Small apartments still need a heating system, a front door etc. Besides there are relatively a lot of walls, so the total size matters for sure*.'(Interviewee 2, 2024) At bigger apartments it is expected to be feasible, however it will still be more difficult than normal houses.

Furthermore in the literature study it was stated that the floor height influences the amount of façade needed(Arnoldussen et al., 2023). Although people prefer high ceilings in general, this is unpreferable for the developer, since this means a bigger building with more material(Interviewee 1, 2024). The amount of GFA stays the same, so this only increases the MPG-value. In practice most of the contractors and developers always use the same height for their projects. This has to do with standardized elements in the building, for example the stairs. If the floor height would be different for every project, they would have to design new stairs every time(Interviewee 3, 2024).

Another form factors that was mentioned in the literature study was the shape of the façade. A simple straight façade requires less material than one with offsets, since this influences the length of the outline(Arnoldussen et al., 2023). This also depends on the shape of the building which determines the so-called isoperimetric quotient. This is the ratio between the outline of a shape and its surface, where a square is one of the most efficient ones(Interviewee 3, 2024). A floor plan shaped like a circle would give the optimal outline/GFA-ratio, but makes the floor plan layout a bit more difficult(Bakker, n.d.). The order of efficiency per shape is shown in figure 18 below.

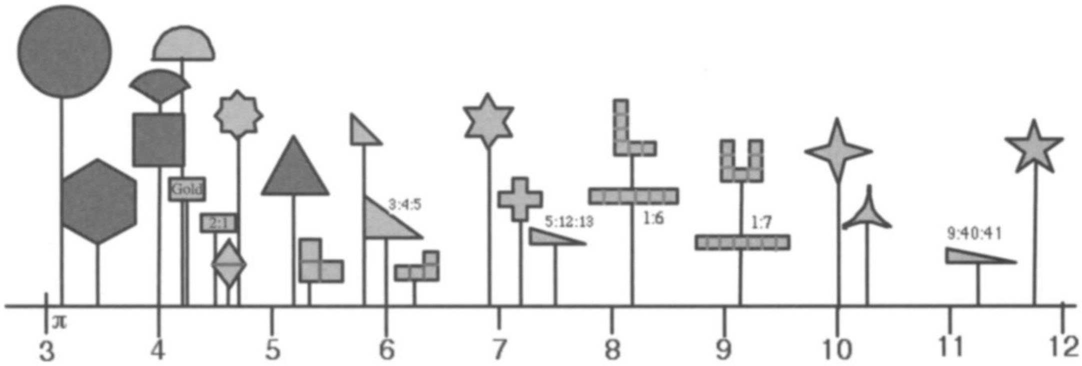

Figure 18: Order of isoperimetric quotients(Apostol et. al., 2004)

Last but not least the type of circulation space, the space that connects the apartments to each other and gives access to them, is also influential for the dimensions of the façade. According to Interviewee 3(2024) an internal circulation space is favorable instead of a gallery. This will also be examined later during the case studies.

7.7 Influence of materials on human health

In chapter 8.3 the comparison between a wooden building and a concrete building was made. When looking at the MPG-value wood seems to be the better material to use, especially when taking the storage of CO_2 into account. Furthermore the use of wood could positively affect the required amount of foundation and it is more suitable for reusing(De Nijs et. al., 2023).

However the choice of either wood or concrete is not only affecting the MPG-value, but it has more consequences that should be looked at. In the Netherlands the health consequences of the materials used in a building are not fully taken into account yet, especially not in the public sector. When the residents health is taken into account it is usually a villa built by private individuals(Interviewee 1, 2024). When looking at developers with large scale-projects concerning apartment buildings for example, the health of the materials will hardly be taken into account. They will mostly choose the cheapest method(Interviewee 1, 2024).

But what makes a building unhealthy? One of the most harmful aspects regarding CO_2 in materials is glue. Nowadays CLT is often mounted together with plastic-based glue. Although the wood in CLT is biobased, the glue can be harmful when it is thrown back into nature. If there was used a biobased glue too, it would be degradable, which positively affects the lifecycle of the material. It should be mentioned that the LCA-calculation method contains a small part of harmful substances, so it is partly taken into account(Interviewee 1, 2024).

However there are consequences and effects of materials directly affecting the health of its residents during the use phase. The so-called biophilic design principle assumes that the human being is a biological animal. '*Human functioning depends on being part of an ecological system of interrelated mutually reinforcing, and integrated parts that constitute a whole greater than its constituent elements*.'(Kellert, 2018). In other words: when designing a building using this principle, it is designed in a natural way that advance both physical and mental health, performance and wellbeing. It is stated that humans feel more comfortable in natural circumstances. Some researches even state that someone sleeping in a wooden room has four heartbeats per minute less than someone sleeping in a concrete room(Interviewee 1, 2024). Interviewee 1: '*In America there are no concrete hospitals built anymore. They are all built with wood and full of greenery to shorten the patients disease trajectory*'. Other materials like bamboo may have the same effect.

Even if concrete is used instead of wood, this can have a natural appearance. Wood often is not even recognizable as wood since it is finished with other layers like water-repellent layers or fire-resistant layers. In many cases these layers are already implemented in the factory, so the wood is never visible on site. Natural esthetics could also be the reason for people to feel comfortable(Interviewee 1, 2024).

Last but not least there is an effect caused by concrete which is known, but not taken into consideration in the Netherlands; Radon gas. This is a gas which accumulates in closed environments and it is a harmful gas that poses a danger to the human health(Bulut & Sahin, 2024). '*The alpha rays released from radon and its decay products, which can enter the body through respiration as a result of its release, constitute internal exposure(an indoor radiation source) for building occupants*'(Bulut & Sahin, 2024).

In short, the health of materials used in a building is underestimated in the Netherlands. Most of the times the cheapest method is used, where the consequences for the health of future residents is completely ignored. Concrete is proved to cause radon gas emissions, which negatively affects the human health.

7.8 The MPG-calculation method

The MPG-calculation should be seen as a means to decrease the environmental impact of a building(Interviewee 1, 2024). By tightening the required MPG-value to 0.5 €/m2.y. the MPG should already be taken into account during the design phase instead of afterwards, which leads to more sustainable real estate in the future. A required MPG-value of 0.8 does not always force designers to think about what materials to use, but when a value of 0.5 is required it is becoming a control instrument which has to be used during the design phase, to be sure the requirements will be met. This should also be the goal of the MPG(Interviewee 3, 2024).

However, the current MPG-calculation methods still has a lot of shortcomings, which have to be fixed before it can be used optimally(Interviewee 3, 2024). First of all clear guidelines of what should be in the calculation and what should not, are missing. When two different people make an MPG-calculation of the same building, it is almost inevitable that they will end up with two different results(Interviewee 1, 2024). For example some calculations contain kitchen furnishing, however this is an aspect that is not required to be included in the MPG, so this only increase the MPG-value unnecessarily. Another example is the amount of solar panels; it is only required to include the solar panels that are needed to meet the BENG-requirements, so the 'bonus'- solar panels can be left out of the MPG. Not everyone is as precise as the other and since there is no regulation, nobody checks the correctness of the calculation made. '*One just calculates the MPG based on the budget without the prices to use the exact amounts of materials, the other just uses a measuring stick for a few hours. Of course this leads to two completely different results'*(Interviewee 3, 2024).

Besides carelessness in calculations the different possible 'product cards' are causing different outcomes. These product cards contain environmental declarations of certain materials. In the NMD there are three categories of these product cards; category 1, 2 and 3. These categories are shown in figure 19. The first category is the most detailed and reliable, since those declarations are drawn up by the manufacturers themselves. Category 2 concerns declarations representing a group of manufacturers, suppliers or a branch. The third category contains declarations drawn up by NMD themselves(Stichting Nationale Milieudatabase, n.d.-b)

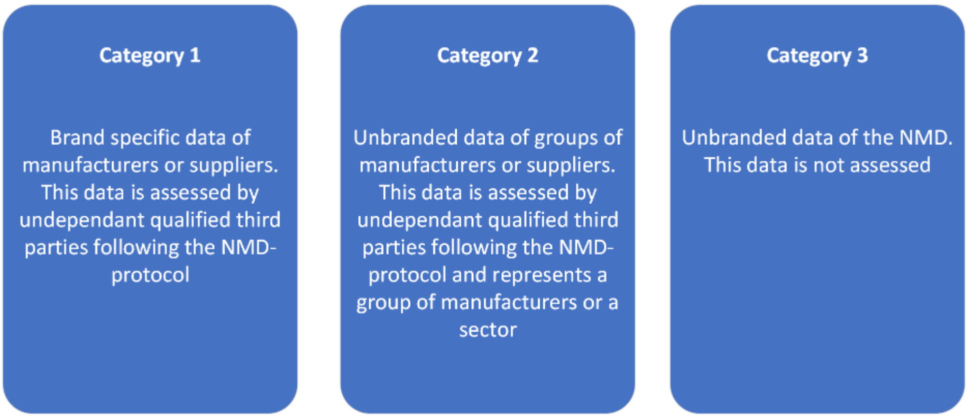

Figure 19: Different categories of materials passports(Own work)

When calculating an MPG-value these product cards are used to represent all materials used in the building, that are also mentioned in the BENG. The NMD can request a manufacturer to draw up a environmental declaration of a certain material that is not registered yet. The NMD can also choose to draw up an environmental declaration themselves which then falls under category 3(Stichting Nationale Milieudatabase, n.d.-b). However, it is preferable to create a product card for category 1 or 2, since manufacturers have more knowledge about their product which makes it more detailed. Product cards in category 3 usually are more rough. To stimulate manufacturers to create a product card of category 1 or 2, the product cards of category get a surcharge of 30%. Besides this is also meant to prevent category 3 of scoring better than the first two categories. However, in practice the product cards of category 3 are still used often because it keeps it a bit vague what materials is exactly used(Interviewee 1, 2024). Interviewee 1(2024) calls it '*creative accounting*'. The product cards of category 2 are often more beneficial than category 1 too, which also takes away the trigger to use product cards of category 1.
In other words; the product cards of category 1 are the most detailed and comprehensive ones since they are drawn up by the manufacturers themselves and they are assessed by an independent third party. However the product cards of category 2 and 3 are often more beneficial for the MPG-value, which makes calculators prefer those categories.

The literature study in chapter 6.4 already revealed some lacks of the current calculation method, for example the underscoring of the use of reused materials.
In 2022 W/E-consultant Rianne van der Veen stated that reusing materials could definitely lead to a lower MPG-value, however this is not always visible yet. Not all products are registered in the NMD(Nationale Milieu Database). In the past few years the NMD is expanding and manufacturers register their products more often. In chapter However one of the d

Another lack of the current calculation method was already touched on briefly in paragraph 8.3; the approximation of wood. In the Netherlands it is assumed that wood has a maximum lifecycle of 75 years, so it is also assumed that after 75 years the CO2 stored in the building is released again when it is burned(Interviewee 1, 2024). The European legislation states that the storage of CO2 in wood can only be taken into account when it has been stored for 100 years, which is not expected to happen in the Netherlands. This means the positive effect of storing CO2 will never be valued. According to Interviewee 1(2024) this is the main reason wood is not scoring a lot better than concrete.

Although this research is focused on the A1-change where the new required MPG-value is 0.5 €/m2.y., it is worth to mention that within the A2-change, discussed in paragraph 8.1, the extra environmental effects that will be added will negatively influence the MPG of wood. This is clearly visible in figure 20 below, where the multiplication factors per material are shown. The mean factor is 2,10, which also explains why the A2-change would contain a required MPG-value of 1.0 instead of 0.5. However wood has a much higher multiplication factor; 2,77. This shows the difficulties the A2-change would cause for buildings using wood. The high multiplication factor of wood is mostly explainable by the emissions of fine dust. These are mostly released during the process of drying of wood, were waste wood is burned(Levels-Vermeer, 2023).

Material	**Multiplication factor difference A1 -> A2**
Plaster	1,57
Concrete	2,25
Wood	2,77
Glass	1,78
Sand-lime brick	2,37
Metals	1,91
Insulation - synthetic	2,85
Brick	2,00
‘Kunststof’ (Dutch)	1,79
Technical installations	1,70
Mean	**2,10**

Figure 20: Multiplication factors per material when comparing A1-change and A2-change (Levels-Vermeer, 2023. Table 9 translated to English)

Last but not least there is the constant change of MKI’s of the materials in the NMD. Every MPG-calculation has its own reference date; the date on which the MPG-value is calculated. This makes it difficult to compare different MPG’s, since one building may scores better than the other on one day and worse on the other. Interviewee 3(2024) mentions an example of a tender that was won based on an MPG-value of 0,44, but when the calculation was refined and updated later, the value suddenly rose to 0,6. It was still the same building with the same materials, but the MKI’s had changed.

In short, the current MPG-calculation method still has a lot of lacks which makes it difficult to compare different MPG’s. The A2-version discussed in paragraph 8.1 contains even more environmental effects than before, which only increases the amount of required research to draw up product cards. According to Interviewee 3(2024) the Netherlands should look to other European countries that use simpler systems; ‘less data, more speed’.

8. Exploring most influential characteristics of apartment buildings on MPG: Case studies

As mentioned before this research contains multiple case studies. To see what elements of apartment buildings have positive effects on the MPG and what elements have negative effects, existing projects or project plans that are yet to be build are studied. The goal of these case studies is to identify the most favorable options that can be used within the building, but the most negative ones too. This information can later be used to create a prototype that meet the required MPG-value of 0.5 €/m2.y.

For the case studies a search frame of 30 to 45 apartments was set, so the projects would be of similar size. However some of the case studies fell outside of this range. These projects are still interesting to look at, since they can show effects on the MPG of an increase in the amount of dwellings. All case studies regard apartments with a size of +- 85 m2 to +- 110 m2.

In Appendix A the MPG-calculations of the case studies are shown. First of all they are divided into the different phases of the project: production phase, construction phase, user phase, disposal phase and outside of the life cycle. For each of these phases the part of the MPG-value can be seen. Furthermore the MPG-value is divided among all main elements of the building. This does not only show the difference between the case studies, but also indicates the most influential elements of the building regarding the environmental impact. For example, the floors and the electrical installations contain a much bigger part of the MPG-value than the roof for example. This can give an idea of what knobs could best be turned to improve the MPG.

Besides the physical elements used in the building, the form factors are also relevant aspects impacting the MPG, as was already discussed in the literature study. Therefore these were identified in these projects as well. First of all there was looked at the total GFA of the building, since this is directly involved in calculating the MPG-value. Although there was set a certain range, the amount of dwellings in the building is also shown in the table. Case study 4 is an outsider regarding the GFA, the amount of apartments and the amount of building layers, however this could also give useful insights in the influence of the size of the building.

With these two characteristic the amount of GFA per apartment in square meters was calculated. It should be taken into account that the circulation space of the building was included in this number. Furthermore the floor height is shown in the table, since this is influential for the amount of façade that is used per m2 GFA.

In the literature study various strategies from the Lente Akkoord 2.0 were mentioned. Some of these strategies are more difficult to assess than others. By comparing the ratio between the surface footprint and the outline of the building the form factor mentioned in chapter 3.2 could be assessed. ‘a simple straight façade contains less materials than a façade with offsets’(page 7). For both the GFA and the outline the ‘average’ floor was taken. In other words; a floor that was most comparable to other floors was taken, so it contained the average amount of circulation space, apartments and balconies for example. In most cases this was the first or second floor.

Furthermore the amount of layers of every project is mentioned in the table. This is especially influential for the height of the building, which at his turn influences the required foundation and construction. The amount of circulation space in square meters was also measured, since these spaces have different needs and requirements than the apartments, which could possibly be influential for the MPG. I compared this amount of circulation space with the GFA of the 'average' floor which resulted in the percentage of circulation space. Since the different case studies do not have the exact amount of GFA, this makes comparing the amount of circulation space easier.

Last but not least, the balconies, roof terraces and galleries from the projects were examined. First of all, the amount of outdoor space was measured at the 'average' floors. The outdoor space contains balconies and roof terraces. For that reason these 'average' floors were taken since the ground floor (usually) does not have balconies or roof terraces. By comparing these numbers to the GFA of these 'average' floors, the percentual amount of outdoors space was calculated.

8.1 Casestudy 1

The first project is located in the province of Noord-Holland. It contains a 5-layer apartment building with 34 apartments, which is being built in 2024. With an MPG-value of 0,746 -value of 0,746 €/m2.y it would not have met the future required MPG-value of 0.5. What could have be done better and what factors were sufficient?

This MPG is mostly negatively influenced by the use phase (0,297), which seems to be especially caused by the interior walls(Appendix A). Furthermore the foundation of the building causes an increase(0,075). Compared to other case studies this building scores well on the construction(0,004), which contains columns and beams of steel. This is often used at projects of this construction company, for example in case study 2 and 3. The materials mainly used in this project are concrete and steel and it was prefabricated.

In the plan of the building(Appendix B) the square-shape is clearly visible, which is beneficial for the GFA/outline-ratio(6,496)(Appendix A). When comparing the form factors of the building it could be defined as an average project among the selected case studies. For example looking at the average size of the apartments(101,74 m2), the percentual amount of circulation space(12,88%) and the GFA(3459 m2) it is quite average without outliers(Appendix A).

8.2 Casestudy 2

The second case study concerns an apartment building in the North of the Netherlands. This project has the same year of construction as the first case study and it has 34 apartments, which is comparable to the amount of apartments in the first case study. However the average size of the apartments in this case study are smaller(Appendix A). The MPG-value of this case study is 0,787 which means this would not meet the required value of 0.5 either. However this is a good reason to look into it and spot the lacks.

In this case the production phase has a remarkably high share of 0,61 €/m2.y in the total MPG. As shown in Appendix A this is mainly caused by the floors, construction and facades. When looking at the form factors the GFA/outline-ratio seems to be the main factor causing this; the six layers containing a GFA of only 2581 m2 result in a ratio of 4,263 m2/m which is the lowest of all case studies. This is mainly caused by the elongated rectangle shape of the plan(Appendix B). As explained in the literature study(chapter 6.2) this means there is relatively much façade needed for the amount of square meters GFA. Since all apartments still need to be accessible and this requires a long hallway, this leads to the highest relative amount of circulation space(16,99%).

Furthermore the relatively high amount of building layers requires a heavier construction, which even leads to the highest MPG-share for construction of all case studies. Last but not least the plan of this building is characterized by the gallery that provides access to the apartments. The consequences of a gallery for the MPG-value will be studied later in this report.

8.3 Casestudy 3

The third selected case study is also located in the North of the Netherlands. It has not been built yet, but construction is expected to start in 2024. This apartment building contains 7 floors, which makes it the second-highest building among the case studies. In the building there are 47 apartments with an average size of 99,77 m2.

As shown in the picture above the façade of this building is not made of one material. The use of various materials makes the MPG-calculation more complex. However this project has an MPG-value of 0.545 which is almost enough to meet the required 0.5 €/m2.y. When looking at the MPG-scores per main element, there are no remarkable values, but the elements that are most influential for the MPG, like the foundation, floors, construction and facades are scoring reasonable. This is also the case for the climate installations and electrical installations. The lack of outliers lead to an MPG-value that is getting close to 0.5.

When looking at the form factors a low relative amount of outdoor space is visible(7,57%). The plan in Appendix B shows quite small balconies of 6,4 m2 or 7,9 m2. The influence of the amount of outdoor space will be analyzed later in this report. Another remarkable value is the GFA/outline-ratio, which is 6,257. This is the one of the highest ratio's of all nine case studies. The plan shows that the shape of this building gets close to a square, which is causing this high value.

8.4 Casestudy 4

This 13-floor apartment building concerns an outsider among all case studies, since it has 106 apartments. All case studies are within the range of 29 to 56 apartments except for this one. It was selected anyway to see whether this leads to a better MPG-value. With an MPG-value of 0.517 it would almost meet the future requirement. The project is located in the province of Noord-Holland. Although the picture above gives a clear image of the building the year of construction is not determined yet.

In chapter 6.2 of this report the literature study stated that higher buildings require heavier foundations and constructions and therefore have higher MPG-values. However, this case study's foundation has the lowest MPG-share of all case studies, which contradicts the literature. The foundation is made of the same material as the first three case studies. This concerns beams and poles of prefab concrete. The facades(0,097) and electrical installations(0.54) are scoring slightly above average(Appendix A).

The number of apartments results in a substantial GFA: 9095 m2. Since this is divided among 106 apartments, the size of apartments is relatively small compared to other case studies(85,8 m2). This does not lead to a bigger influence on the MPG of interior walls, which would not be surprising. The big hallway on every floor of the building results in a percentual amount of circulations space of 14,12% which is the second highest percentage of all case studies.

8.5 Casestudy 5

Case study 5 is a project located in the South of Holland, and it is mostly built with wood. This 5-floor apartment building consists of 56 dwellings with a total GFA of 5984 m2. With an MPG-value of 0,477 €/m2.y this project would meet the future requirements too, although this is not necessary yet since it will already be constructed in 2024. An important sidenote of this project is the NMD-reference date: 14-7-2021. This is two years earlier than most of the other case studies, which makes the low MPG-value more difficult to compare, since the MKI's could have changed considerably in the meantime.

The MPG-value of casestudy 5 is mostly positively influenced in the production phase(0,273), construction phase(0,014) and disposal phase(-0,018). In Appendix A this is visible when comparing these numbers to those of the other case studies. The most remarkable aspect of this case is the negative result in the disposal phase, since this phase contains demolishing and processing of materials. This surprising outcome was checked with W/E-Adviseurs and according to them it is very unlikely that this value is correct.

When looking at the main elements in the building and their individual environmental impact, the facades and roofs are scoring well. The score of the facades is probably because of the high GFA/outline-ratio(6,13), which is in this case not caused by a square-shaped plan. However this project also has the highest floor height of all case studies(3,145), although this is only a small difference(Appendix A). Nevertheless, an increase in floor height also increases the dimensions of the façade and with that the required amount of materials too. The project has a footprint of 1397,71 m2 which is by far the biggest of all case studies. It does not only have the biggest footprint, but the biggest outline too(222,92 m).

The negative impacts on the MPG are mostly coming from the electrical installations(0,149). This is causes by approximately 400 m2 of solar panels. However these are not necessary to include in the calculation, since they are not included in the BENG-calculation either. This means the total MPG-value of this building could have been even lower.

8.6 Casestudy 6

KNOEST, Pijnacker

MPG: 0,372
NMD-reference date: 2-8-2023
Year of construction: 2025
Amount of apartments: 29
Total GFA: 3225 m2

This case study concerns a project called ‘KNOEST’ which is developed by Revolve Development, and is located in Pijnacker, in the province of Zuid-Holland. This 5-floor apartment building contains the biggest apartments of all case studies(111.21 m2 incl. circulation space) and will be constructed in 2025. This building is built with wood and has an MPG-value of only 0,372 €/m2.y., far below 0.5. Other strategies used for KNOEST are the use of biobased-materials apart from wood, reuse of materials and more intensive industrialization(*Knoest wonen - Nieuwbouw in Pijnacker*, n.d.).

In the building wood is applied in different ways; the main structure consists of CLT massive walls and floors, the interior walls are made of ‘HSB’(Timber Frame Construction) and for the interior doors and window frames there was used wood from sustainably managed forests(Stichting Nationale Milieudatabas, n.d.-b).

The impact of wood is mainly visible in the MPG-value of the foundation(0,014), the floors(0,045), the construction(0,024) and the roof(0,014). As discussed in chapter 8.1 a wooden construction has less weight than a concrete one which requires less foundation. The favorable values of the floors, construction and roof are mainly because of the production phase, which is also visible in the MPG-share of that phase itself(0,181). Of all nine case studies, this production phase is the lowest. Furthermore this project has the lowest floor height, together with case study 7, 8 and 9. They all have a floor height of 3,000 meters(Appendix A).

The GFA of 3225 m2 is divided among 29 apartments and as can be seen in Appendix B the floor plan has quite the shape of a square. Nevertheless the GFA/outline is no more than average(6,031). This could be caused by the relatively small balconies, which make the outline increase relatively more than the GFA. The low percentage of outdoor space compared to the footprint(8,95%) confirms this(Appendix A).

8.7 Casestudy 7

Casestudy 7 concerns an apartment building in the province of Zuid-Holland and it is focused on elderly people. The construction started at the end of 2023 and the building will contain 39 apartments with an average size of 102,05 m2 including circulation space. The total MPG-value is calculated at 0,608 €/m2.y., although it gets close to the new requirements, it would not meet them.

When looking at the influence of the production phase(0,352), this project does not score badly compared to other case studies. Meanwhile the disposal phase has an MPG-value of 0,057 €/m2.y which is the worst of them all. This means that materials are often used that have a bad environmental impact when destroyed and less materials are used that could be reused or recycled for example. Furthermore the climate installations represent a large share in the MPG; 0,106 €/m2.y. This is mainly caused by 40 heat pumps(0,039 €/m2.y) and 40 water boilers(0,040 €/m2.y). Furthermore the MPG-value of the interior walls has a relatively small share, which could be explained by the presence of a gallery, since a gallery makes access to the apartments possible without the need for interior walls.

The floor plan shows an elongated rectangle shape with a gallery giving access to the apartments. Despite the fact that this shape is unfavorable regarding the GFA/outline-ratio, this ratio is still 5,817 m2/m, which is approximately average compared to the rest of the case studies. The balconies that are mainly located within the edge of the façade have a positive influence on this, since they do not extend the outline.

8.8 Casestudy 8

Case study 8 concerns a project in the province of Zuid-Holland, which is the same province as the previous case study. This apartment building contains only 3 floors with 22 apartments in total and it is built at a site which previously contained a school. It almost meets the required MPG-value of 0.5 €/m2.y but it falls short by 0,02. The construction of this project is expected to start in the second half of 2024.

This project does not score badly on particular phases of the project(Appendix A). However it does have one outlier among the main elements: the foundation(0,086). This is the highest MPG-value for the foundation of all case studies. This could be caused by the fact that it has only 3 floors, while a foundation is still needed. This could mean that there is relatively much foundation per floor needed.

Furthermore the floors has quite a high MPG-value(0,159), which could have something to do with the remarkably big share of concrete prefab balconies(0,030 €/m2.y). The fixed facilities of this project, containing for example the sanitary facilities and the kitchens, has the highest value of all case studies. However this seems to have to do with the NMD-reference date. For example when comparing the fixed facilities to case study 7, 22 showers and toilets of the case study 8 have a worse score(0,05) than 40 showers and kitchen of case study 7(0,02). Nevertheless this is a very small part of the total MPG-value.

Looking at the form factors of this building it has the lowest GFA of all case studies, mostly due to the low number of floors. Just like case study 7 and 9, there was chosen a floor height of 3,000 meters and there was used a gallery to provide access to the apartments. A factor where something could have been gained is the shape of the building, since the elongated shape causes a quite low GFA/outline-ratio: 5,214 m2/m. If the shape would have been more of a square the MPG-value could possible have been lower than 0.5 €/m2.y.

8.9 Casestudy 9

The last case study concerns an apartment building also located in the province of Zuid-Holland, just like the two previous projects. The building is part of a project containing two buildings; a 4-floor apartment building with 40 apartments and a 3-floor building with 31 apartments whose construction will start in 2024. For this case study there will be looked at the first building: building A. With a total MPG-value of 0,471 €/m2.y this building would meet the future required value of 0.5, which is mostly thanks to the remarkably low shares of the use phase(0,063), which at his turn is caused by the good scores of the installations(0,015 and 0,018). The building contains 40 apartments with an average size of 108,45 m2 including circulation space and has a total GFA of 4338,1 m2.

These apartments are all heated via the city's shared heat network, which does not have any impact on the MPG-value at all(0,00). This means the MPG-value of the climate installations only represents the impact of the floor heating systems and the ventilation systems. Regarding the electrical installations this project also scores best of all nine cases.

The floor plan of the building is a very elongated rectangle, only 11.28 meter wide and 64,8 meters long, which is disadvantageous for the GFA/outline-ratio(4,958). In combination with the big amount of relatively small balconies located outside of the outline, this makes it the lowest of all case studies. Nevertheless these balconies do lead to the highest percentage of outdoor space in the end(16,54%)(Appendix A).

8.10 Discussion on case studies

The goal of studying these nine reference projects was to reveal the most influential choices that can be made within the design of a building. By identifying the main buttons that can be turned, a basis for the prototype was laid. The prototype will be discussed in chapter 10.

To identify these main buttons several t-tests were executed. A t-test is a tool that can be used to evaluate the means of one or two different populations. In this case a so-called independent two-sample t-test is used, since two different groups are tested. For the t-test the nine case studies were divided into two groups based on different criteria, mostly form-factors. The MPG-value per phase and per main element were compared to see whether this caused differences and if yes, what differences(Two-sample T-Test, n.d.). The results of the t-tests are shown in Appendix B.

8.10.1 Main material

First of all the case studies built with wood were compared to the projects built with concrete. The biggest difference in MPG is caused during the production phase where the mean MPG of the wooden projects is 86,6% less than the mean of the concrete projects(Appendix B). This advantage can be explained by the fact that wood is a biobased material and concrete is not. The 'production' of wood therefore has a much smaller environmental impact than the production of concrete.

When looking at the main elements all heavy elements score a lot better using wood. The floors, the construction, the facade and the roof all have MPG-values that are less than half of the MPG-value of concrete. The foundations of all nine case studies are made of concrete, but it is clearly visible that the foundations of the wooden projects are lighter(-173,95%) than the ones of concrete projects(Appendix B). The total mean MPG-value of the wooden projects is 40.54% lower than the mean MPG of the concrete projects.

8.10.2 Size of apartments

To see the influence of the size of apartments there was made a division between projects with apartments smaller than 95m2 and ones with apartments bigger than 95m2. This did not result in a big difference between the total mean MPG-values: 3,45% in favor of the bigger apartments. Nevertheless there were two surprising differences regarding the MPG-values of the interior walls and climate installations. The smaller apartments scored better on both of these, while it was expected that apartment building containing smaller apartments would relatively have more interior walls and climate installations.

8.10.3 Number of apartments

Thirdly the number of apartments was analyzed. The first group contained case studies with less than 35 apartments, the second group contained case studies with more than 35 dwellings. Among the different phases no remarkable differences were visible. When looking at the main elements of the buildings the façade and roof of the projects with more than 35 apartments score +-35% better, since both can be divided by more square meter GFA which turns out to be more efficient. A remarkable difference is the difference regarding circulation space. The group with less than 35 apartments scores 49,33% better, however their relative amount of circulation space is not particulary higher than the amount of circulation space in the group with more than 35 apartments(Appendix A). This t-test resulted in a difference of 12,99% in favor of the group with more than 35 apartments.

8.10.4 Gross Floor Area

Then the influence of the total Gross Floor Area was analyzed, which is largely related to the number of apartments. The first group contained projects with a GFA lower than 4000 m2, while the second group was bigger than 4000 m2. The difference between the mean MPG-values was almost the same too: 11,70% in favor of the bigger GFA. A remarkable difference was visible in the disposal phase, which was 82,67% in favor of the bigger GFA. This could be caused by the fact processing waste on a large scale works more efficiently than on a smaller scale. Furthermore, the heavy elements like the foundation, the floors, the facades and roof all scored better for bigger GFA's, but the construction of the projects with smaller GFA's scored much better(79,37%)(Appendix B). This does confirm the expected consequence of higher buildings discussed in paragraph 6.4. In conclusion a bigger GFA is favorable for the MPG-value.

8.10.5 Amount of circulation space

Furthermore the amount of circulation space as a percentage of the GFA was studied. This contained the hallways, galleries, lobbies and staircases outside the apartments. The groups were split at 13,5% circulation space. In Appendix B a remarkable difference is visible regarding the construction. The group of projects with less than 13,5% circulation space scores 92,82% better than the projects with more than 13,5% circulation space. However in the end the second group has a total mean MPG-value which is 5,53% lower than the first group, which is a pretty small difference. This benefit was mainly achieved outside of the building lifecycle(Appendix B). The difference here was 45,32%. No direct explanation for this could be found.

8.10.6 Amount of outdoor space

Besides the amounts of circulation space the amounts of outdoor space were compared too, containing galleries, balconies and roof terraces. The first group contained all case studies with less than 10% outdoor space calculated from the total gross floor area. The second group was bigger than 10%. Clear differences were visible when looking at the heavy elements like the floors, the construction, the façade and the roof. They were all scoring better within the group with less outdoor space. This could be caused by the fact that large balconies, increasing the amount of outdoor space, complicate the outline of the building, affecting these heavy elements. However these benefits were all compensated by the installations that were all scoring better at the projects with more than 10% outdoor space(Appendix B). This can be explained by the fact that outdoor spaces are included in the GFA, but do not require any installations.

8.10.7 GFA/Outline-ratio

This form-factor was already discussed in both chapter 6.2 and chapter 8.6 and influences the amount of façade needed. To compare the relationship between the GFA of the building and its outline, this GFA/outline-ratio was calculated: how many m2's GFA per meter outline does the building have. Group 1 of this t-test contains the projects with a ratio below 5,3 m2/m and group 2 contains the ones with a ratio above 5,3 m2/m. The biggest difference can be found in the use phase, especially due to the installations. The MPG-value of the projects with a ratio below 5,3 scores more than 100% better than the one of the projects with a higher ratio. Nevertheless, this seems to be due to the small GFA's of the projects within group 1(average gr.1 = 3053,8 m2, average group 2 = 5072 m2). For this reason these projects require less installations. A higher GFA/outline-ratio does lead to a better MPG-value for the heavy elements, like the floors and the façade. In total a ratio higher than 5,3 leads to a total MPG-value which is 7,24% higher than a ratio lower than 5,3(Appendix B).

8.10.8 Gallery

Another aspect that makes the case studies differ from each other was whether they contained a gallery or not. Especially the MPG-values of the floors differed a lot: 42,81% in favor of the buildings without a gallery. The floors of balconies and galleries are included as a separate element in the MPG-calculation, which causes a surprisingly high increase in the MPG. For example in case study 7 the MPG-value of the balconies and galleries only is 0,020 and for case study 9 this is even higher: 0,038. Furthermore the installations score better at the projects with a gallery, which is probably caused by the fact that the buildings without a gallery contain hallways and other internal circulation spaces, that need installations to maintain a reasonable climate. Of course, this is not needed for galleries. The difference between the total mean MPG-values of these groups is 10,24% in favor of the projects without a gallery, which is a relatively big difference.

8.10.9 Floor height

Last but not least there is the floor height, which was also discussed in paragraph 8.6. It would be influential for the amount of façade needed(Arnoldussen et al., 2023). Since the amount of GFA remains the same the MPG-value is expected to decrease when decrease the floor height. Among the case studies there was little difference between the floor heights. Four projects have floor heights of 3,008 meters, four other projects have floor heights of 3,000 meters and one case study has a floor height of 3,145 meters. For this t-test group 1 contains the buildings with floor heights of 3,000 meters and group 2 contains the buildings with floor heights higher than 3,000 meters. There was a significant difference visible in the production phase, in which group 1 scored 30,72% better than group 2. This difference is 17,86% of the total mean MPG-value. The elements that were saving the most environmental impact using a lower floor height are the construction, the interior walls and the façade(Appendix B). This could be explained by the fact that when lowering the floor height, the building is less high, which requires less materials while the GFA remains the same. When looking at the total mean MPG-value group 1 scores 23,96% better than group 2.

8.10.10 Overview of most influential factors

In figure 21 below all percentual differences between the two groups of all t-test are shown. In the left column the criteria are shown, the middle left column shows the favorable choice and the middle right column the percentual advantage. This percentual advantage is purely based on the difference between the two groups, however it may not be a big share of the total MPG-value. For that reason the right column shows the percentual share of this difference of the total mean MPG-value of all case studies, which is 0.558 €/m2/year.

Criteria	Favorable choice	Percentual difference	Difference as a percentage of total mean MPG-value
Main material	Wood	40,54%	30,82%
Floor height	< 3 meters	23,96%	21,14%
Number of apartments	> 35	12,99%	14,00%
Total Gross Floor Area	> 4000 m2	11,70%	12,18%
Gallery?	No	10,24%	10,85%
GFA/Outline-ratio	> 5,3	7,24%	7,61%
Amount of circulation space	> 13,5%	5,53%	5,67%
Size of apartments	> 95 m2	3,45%	3,52%
Amount of outdoor space	< 10%	1,46%	1,40%

Figure 21: Results of t-tests sorted at percentual differences(Own work, 2024)

Based on the case studies the choice of the main material and the floor height are the two most influential factors for the MPG-value. Choosing wood instead of concrete as main material could lower the MPG-value with 30.82% and a maximum floor height of 3,000 meters instead of higher could lower it by 21,14%. The number of apartments and the total GFA are directly related to each other and are preferable to be big(> 35 apartments and GFA > 4000 m2). Furthermore, a gallery is not preferred. The GFA/outline-ratio and the amount of circulation space proved to have some influence on the MPG, but only to a certain extent. According to these case studies the size of the apartments and the amount of outdoor space does not matter enough to tailor the design accordingly.

8.10.11 Analysis of variance

These t-test gave a good image of the most influential factors based on the nine case studies that were picked. However they only tell which way you should go; 'there should be more than 35 apartments', 'the floor height should be less than 3 meters' etc. To get an image of what would be the best option according to these case studies, the t-tests were done the other way around. The case studies were divided in three groups based on their MPG-value. Since the t-test can only be done with a maximum of two groups, this is done via an analysis of variance(Spotfire, n.d.) where the means of multiple groups are compared to each other. In Appendix E this analysis of variance is shown.

The first group contains all case studies with a total MPG < 0.5, so all case studies meeting the future required value of 0.5 €/m2.y. The second group contains the case studies with MPG-value between 0.5 and 0,7 and the third group contains the projects with MPG-values above 0,7. When looking at the means of the form factors per group some patterns can be recognized.

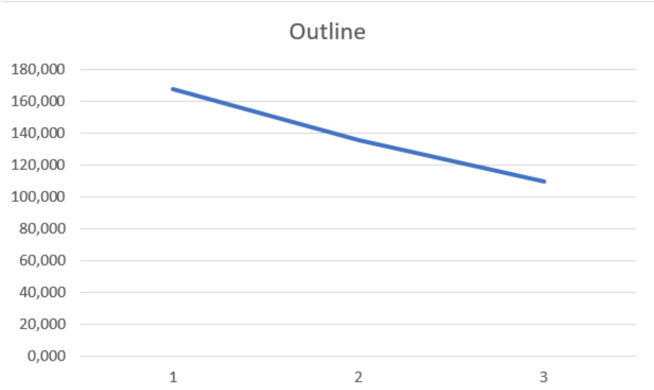

Figure 22: Outline in relation to the MPG(Own work, 2024)

The first pattern can be seen at the outline, which is shown in the figure above. It shows that according to the case studies, the larger the outline the better the MPG-value, since group 1 contains the best MPG-values.

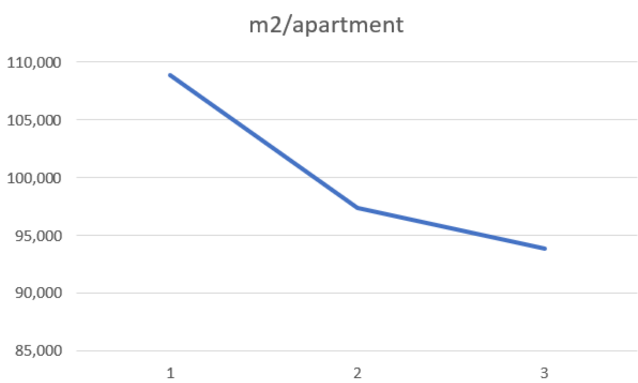

Figure 23: Size of apartments in relation to the MPG(Own work, 2024)

Another pattern was recognized within the relation between the average size of apartments and the MPG-value. Figure 23 above shows a declining line as the MPG-value increases. In other words this graph shows that bigger apartments are beneficial for the MPG.

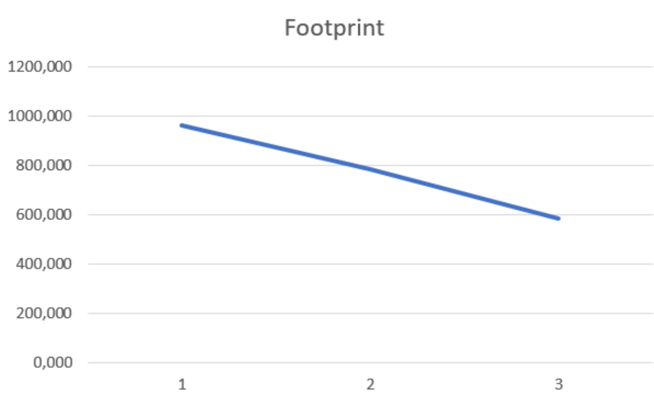

Figure 24: Footprint in relation to the MPG(Own work, 2024)

The size of apartments is often related to the footprint, although the number of apartments and the number of floors affects this too. However figure 24 shows the influence of the footprint in m2 on the MPG-value. As shown in figure 24 the projects in group 1 had an average footprint of 963 m2, which is much higher than the average footprint of group 3: 585 m2(Appendix E).

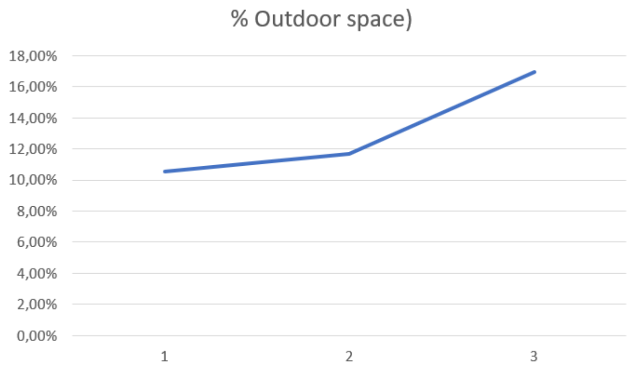

Figure 25: Percentual amount of outdoor space in relation to the MPG(Own work, 2024)

In paragraph 9.10.10 the overview of the most influential factors on the MPG showed that the amount of outdoor space is hardly affecting the MPG-value. Nevertheless, the analysis of variance shows a pattern where a lower percentage of outdoor space improves the environmental performance. As figure 25 shows, group 1 has an average percentual amount of 10.5% while this is almost 17% for group 3(Appendix E).

The patterns regarding the outline, size of apartments and footprint shows the relevance of the size of the building. Other factors about the size, like the total GFA and the amount of building layers did not contain a clear pattern(Appendix E). However the means of these factors for group 1 can be used as favorable values for the design of the prototype.

9. Exploring possibilities: Prototype

Figure 26: Prototype apartment building(Own work, 2024)

9.1 Specifications

Based on the lessons learned from the case studies that are showed in figure 21, a prototype of an apartment building is designed. This prototype is focused on having an MPG-value as low as possible. This means it was not designed to be practical and it will not be brought to the market.

First of all the shape and dimensions of the building were determined, using the favorable choices of figure 21 and the analysis of variance showed in Appendix E. The floor height was set at 2,900 meters, based on the minimum of 2,600 meters mentioned in the building code. The thickness of the floor itself is assumed to be 300 millimiters. To get a high GFA/Outline-ratio a square-shape was chosen with a sides of 32,5 meters. After including the balconies this gives a footprint of 1156,03 m2. Figure 24 showed the relation between the footprint and the MPG, where group 1 containing the best MPG-values had a mean footprint of 963 m2, which is comparable to the footprint of the prototype. The analysis of variance gave an ideal number of building layers of 4,67 where group 2 and 3 both had higher means, so for the prototype a number of 4 building layers was chosen. This leads to a total GFA of 4624, 12 m2 which also follows the favorable choice of a GFA > 4000 m2(figure 21).

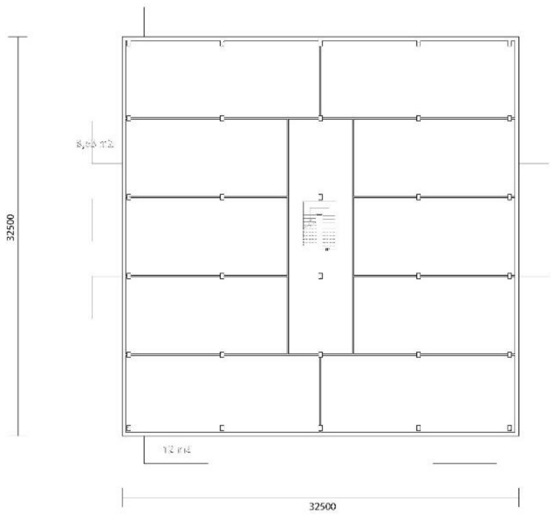

Figure 27: Floor plan 1st, 2nd and 3rd floor prototype(Own work, 2024)

As the floor plan in figure 27 shows every floor contains 10 apartments resulting in a total of 40 apartments. On the ground floor the hallway in the middle is extended to the entry, which downsizes two of the corner apartments a bit. The circulation space in total is an average of 8,68% of the footprint. This is measured for the floor plan of the 1st, 2nd and 3rd floor(figure 27), so if the ground floor is included the average percentage will increase a bit.

Figure 28: Interior impression(Own work, 2024)

In Appendix D the MPG-calculation of the prototype can be found. This calculation shows the materials and the amount of materials that are used. The amounts are estimations based on the dimensions of the floor plans and heights. In some cases where it was hard to make estimations reference projects out of the case studies were used.

Figure 29: Exterior impression prototype(Own work, 2024)

Apart from the foundation no concrete is used. The floors are made of HSB(Timber Frame Construction), wooden beams and wooden 'kanaalplaatvloeren'. For the columns 'laminated European coniferous wood' is used. The interior walls are made of wooden 'chipboards'. Furthermore the façade was finished with European coniferous wood multiplex(Appendix D & figure 29).

9.2 Heat pump

Appendix D contains two different MPG-calculations of the prototype apartment building, one resulting in 0,421 €/m2.y. and the other resulting in 0,630 €/m2.y(figure 30 & 31). This difference is caused by the heat generation. Both versions use a heat pump to generate heat for the building and a floor heating system to distribute heat. However two different ways of calculation are used for the heat pumps.

In February 2023 the NMD concluded that the environmental impact of heat pumps is bigger than expected. Wen they made an update of the data that was used in the past, the MPG-values of heat pumps turned out to have risen so high now, it is almost impossible to meet the future required MPG-value of 0.5 if these data would be implemented in the MPG-calculation method. For this reason these current data of installations are not usable(Van Gastel, 2023).

Therefore the NMD introduced a temporary 'compensation factor'('verrekenfactor' in Dutch), that makes it possible to still achieve a reasonable MPG-value, until they come up with a definitive solution. On January 1st 2024 the compensation factor was adjusted and limited to heat pumps with a maximum power of 4,0 kW. This compensation factor will be valid until December 31st 2024(Stichting Nationale Milieudatabase, n.d.-a).

Since it is not known yet whether the environmental impact of heat pumps will be fully counted within the MPG-calculation from January 1st 2025, the MPG-value of the prototype is calculated for both scenario's. If the current compensation factor is used, assuming a 4,0 kW heat pump has enough power for these apartments, the MPG-value is 0,421 €/m2.y., but if the environmental impact of this heat pump is fully counted without a compensation factor it will not meet the maximum MPG-value of 0.5, since it then result in a value of 0,630 €/m2.year.

Figure 30: MPG-calculation of prototype using the compensation factor(GPR Material, 2024)

Figure 31: MPG-calculation of prototype without using the compensation factor(GPR Material, 2024)

10. Developers view on prototype

Based on both multiple interviews and case studies the most effective factors to improve the MPG of an apartment building were identified. The influence of the buttons that can be turned was indicated and on that basis a prototype was designed, including an MPG-calculation. Assuming the compensation factors can be used, this prototype meets the future required MPG-value of 0.5.

As mentioned in paragraph 10.1 this prototype was focused on achieving an MPG-value as low as possible and it is not meant to be brought to the market. However to indicate whether an apartment building with an MPG-value below 0.5 €/m2.y. is feasible for a the market too, the prototype was presented to a developer. The goal was to identify the feasibility of the prototype for developers.

To do so, an interview was conducted with Interviewee 3, who is plan developer at a construction company. According to Interviewee 3(2024) a building with a low MPG-value is not only useful since it should meet the requirements but it can also make you win a tender. Tender are often mostly about the lowest costs or about the schedule, but the role of the MPG-value of projects is increasingly important.

10.1 Form factors

As mentioned in paragraph 10.1 the square-shaped floor plan has sides of 32,5 meters and since every floor has 10 apartments that all require daylight, the dwellings are relatively deep. '*Getting enough daylight in these dwellings will be a challenge, especially because the daylight is obstructed by the balconies.*'(Interviewee 3, 2024). The prototype contains a floor plan where every dwelling has a living room and one of the bedrooms on the wall side, so provided with daylight. The second bedroom, the bathroom and the technical space do not have any windows(figure 32). This means regarding daylight a three-room apartments is actually not possible. The corner rooms never give problems regarding daylight(Interviewee 3, 2024).

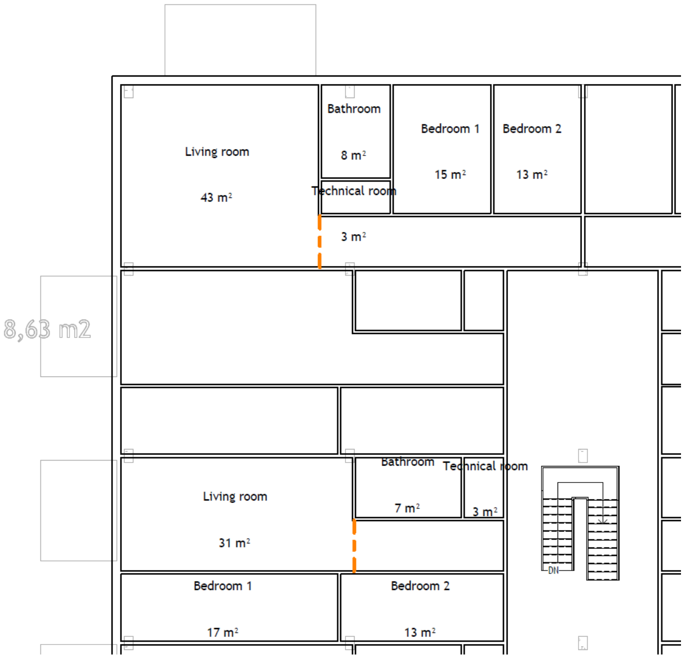

Figure 32: Floor plan of individual dwellings(Own work, 2024)

Interviewee 3(2024) also agrees on the square-shaped footprint. This is one of the most efficient ones. The choice to not use a gallery as circulation space, which was one of the favorable choices based on the case studies, was also appreciated. '*An internal circulation space requires little façade. This is more efficient than a gallery*'(Interviewee 3, 2024). Furthermore the amount of apartments seemed right too(Appendix A).

When looking at the construction of the building some aspects are a bit doubtful. '*The span of CLT is a lot more limited compared to concrete. This prototype has a span of 6,5 meters, which may not be possible, at least not in a cost-efficient way. I think you should add an extra carrying line in the construction'*(Interviewee 3, 2024). An extra carrying line will require more columns which at his turn leads to more material, so this will affect the MPG-value. Interviewee 3(2024) also points out that the staircase often has a lot of regulations regarding the fire safety. These safety measures could lead to extra doors, but will only have a small impact on the MPG-value.

10.2 The housing market

Besides the question whether the form factors would be realistic and practical, it is also interesting to look at the current housing market; is this type of apartment even in demand? The average size of the apartments in the prototype apartment building is 114,95 m2 including circulation space. When excluding the 8,61% circulation space this would result in approximately 107,35 m2(Appendix A). According to Interviewee 3(2024) these apartments may be a bit too large for the current market. '*At this moment there is a large demand for smaller apartments, about 65-70 m2. To make the apartments smaller the façade of the prototype you would have to bring the façade in, which changes the form factors of the building*.'

11. Discussion

The main research question of this report was: *How can apartment buildings be designed with an MPG < 0,5 and with what impacts?*

There were formulated three sub questions that can help answer the main question. In chapter 6 of this report, available knowledge on this topic was collected through literature research. Different scientific papers, reports and articles provided information about ways to improve the MPG that are already known. However most of these strategies were based on expectations. After discussing these expectations in chapter 7 the empirical research started from chapter 8 containing interviews, case studies and the design of a prototype. In this chapter the findings of these methods will be discussed with the aim of answering the research questions.

11.1 SQ1: What are the most influential factors for the MPG?

To determine the factors of the building with the biggest influence on the MPG-value nine case studies were done of four different contractors. Figure 21 shows a ranking of the factors included in this research.

The most influential factor of an apartment building for the MPG is the main material that is used. When comparing the case studies built of wood to those built with concrete the difference was more than 40%. As a percentage of the total average MPG this was almost more than 31%, which shows the influence this design choice could have. The difference was mostly caused during the production phase in the heavier elements of the building, such as the façade, construction and roof(Appendix B).

The second-most influential factor based on the case studies was the floor height. Using a small floor height decrease the amount of façade needed, which is not only visible in the façade's share of the total MPG, but also in the construction, the interior walls and the electrical installations. Although most people prefer to have high ceilings, this actually means you are throwing money out of the window, since you need more material for the same amount of GFA(Interviewee 1, 2024).

Furthermore the size of the building has a considerable influence on the MPG. In this research the size of the building was measured in multiple ways: total GFA, number of apartments and the size of apartments. The number of apartments had the biggest influence(12,99%) followed by the GFA(11,7%). The difference regarding the size of apartments was smaller(3,45%).

Besides the main material, the floor height and the size of the building, the use of a gallery is also influential, which was shown by a difference of 10,85% of the total average MPG. The GFA/outline-ratio was less influential than expected, but could still make a difference of 7,61% of the total average MPG. Factors that are less influential and could therefor be ignored, are the amount of circulation space and the amount of outdoor space.

11.2 SQ2: What strategies are needed for apartment buildings to reach an MPG-value of 0.5?

During the literature research multiple general strategies to decrease the MPG-value were listed. The strategies mentioned were:

- Use of more sustainable versions of materials, for example recycled or hybrid materials
- Use of biobased materials
- Building 'slender' (use less materials)
- Adjust the design to create more efficient form factors
- Expand the lifespan
- Building demountable

These strategies were all pretty general and difficult to measure on existing projects, since most of them are relative. During the case studies the projects were examined more in detail, by decompose the MPG-calculation per main element(Appendix A). Furthermore the impact of specific elements of the buildings was studied, which is shown in figure 21 in paragraph 9.10.10. The case studies showed that the use of wood has the biggest positive influence on the MPG-value, which is relatable to the strategy 'use of biobased materials'. Other biobased materials like natural insulation materials were not even taken into account yet. Since the storage of CO_2 in wood is not included in the MPG yet, this advantage could even be bigger in the future(De Nijs et. al., 2023), although it remains a point of discussion to what extent this is beneficial(Interviewee 2, 2024).

Other influential factors were mostly related to the strategy 'adjust the design to create more efficient form factors'. The floor height for example had an impact of 21,14%(figure 21) and the size of the building, expressed in both the number of apartments and the total GFA, turned out to be rather large than small. The case studies show that the total GFA should be bigger than 4000 m2. It should be said that a bigger size does not have to be better till eternity. This research did not study a possible turning point. Furthermore the circulation space as a gallery is proved to be disadvantageous for the MPG-value, so it is advised to use an internal circulation space.

Another important form factors that should be taken into account is the GFA/Outline-ratio that should be rather big than small. Shapes like a square are most favorable, but the benefit of this is also related to the footprint of the building.

The strategy 'expanding the lifespan' that was mentioned by the Lente-Akkoord 2.0(2023) during the literature research seems to be difficult at this point. In the Netherlands certain materials have a standard lifespan of 75 years, for example wood which is an influential element of the building, if used. This makes it questionable if expanding the lifespan is legally possible. However paragraph 8.5 tested the effectiveness of this strategy on a randomly picked project, which shows that the effect is less than expected since the use phase contains a big share of the MKI.

Furthermore the strategy of building demountable had an expected effect of -0,02 €/m2.y. according to the Lente-Akkoord 2.0(2023). During the interviews it turned out to be difficult to get an advantage out of a demountable building in advance, since it cannot be proved to be demountable. However the building which is reusing materials 1-on-1 from a former building is rewarded, since the production phase of that phase can be crossed away in the MPG-calculation.

Last but not least, an important way to improve the MPG-value is to look closely at the installations in the building. These turned out to be very influential, since especially the heating system has a big share within this MPG-value. Currently there is a multiplication factor for heat pumps with a power of up to 4,0 kW which decreases the MPG-value significantly. This multiplication factor was devised to help smaller dwellings meet the MPG-requirements. However, paragraph 10.2 also showed that without this multiplication factor the required value of 0.5 is almost impossible to meet.

11.3 SQ3: What are the impacts of these strategies for the costs and the living environment?

Subquestion 2 was about the possibility of achieving an MPG-value of 0.5 €/m2.year, which could be possible using various strategies. However, what is the impact of these strategies on the financial side of the project? Do they make the costs increase or decrease or do they remain the same?

In paragraph 6.3 the expected consequences of MPG-improvement strategies were discussed. It was expected that changing the way of building would increase the costs of projects. Especially industrial construction companies would have to adjust their standardized ways of design, which would require some big one-time-investments(Arnoldussen et al., 2023).

On the other hand there were strategies expected to lower the costs, for example building 'slender' would require less materials. The same goes for adjusting the form factors that could decrease the amount of façade needed. However, according to Interviewee 2(2024) the material itself is not the expensive part, but it's the labor. '*If the requirements are tightened, people have to become innovative. Contractors are risk averse, so they are inclined to add 10% to the costs when they have to take a risk by using unknown ways of building. Everyone wants to get rid of responsibility. That is* *what makes it more expensive.*'(Interviewee 2, 2024). Interviewee 1(2024) also states that it is not the materials that are expensive, but it is the research that is needed. Since we are used to building with steel or concrete, other materials require a lot of research regarding fire safety, stability etc. This is only a 'financial threshold' we have to get over(Interviewee 1,2024).

However these strategies are expected to become cheaper again in the future. As soon as the market for new innovative materials grow, an economy of scale will arise(Interviewee 2, 2024). According to Interviewee 1(2024) the costs of biobased materials is already decreasing and is even comparable to traditional materials. He expects the CO2-intensive materials to become more expensive because of CO2-taxes, while biobased materials will be cheaper in the future.

In short, according to experts the expectation of higher costs for innovative materials is not so applicable than expected. If the costs of using biobased materials remain equal to traditional materials and the rent prices or sell price does not change, the financial feasibility of the project is expected to remain the same. It should be mentioned that the impact of the strategies on the rent prices or sell prices (partly) depends on possible consequences regarding the living environment, which will be discussed in paragraph 12.3. To get a full overview of this impact, future research is needed.

This subquestion also concerned the impact on the living environment. This question was mostly answered through interviews and literature research, since it could not be tested. The literature research resulted in an expected improvement of the living environment due to the use of biobased materials. Natural fibre materials such as cork, cotton, wood fibre and hemp have a moisture-buffering capacity(Çetiner & Shea, 2018). These effects were not particularly discussed during the interviews, that were mostly focused on wood as biobased material.

However the use of wood instead of concrete did turn out to be beneficial for the health of the residents. Multiple studies were done on the effect of natural elements on the human health. According to the biophilic design principle 'the human functioning depends on being part of an ecological system of interrelated mutually reinforcing, and integrated parts that constitute a whole greater than its constituent elements'(Kellert, 2018). It is stated that this would improve both the physical and mental health, performance and wellbeing of the resident. Another study even proved that someone sleeping in a wooden room had four heartbeats less than someone sleeping in a concrete room(Interviewee 1, 2024).

Furthermore concrete has a disadvantage which makes the use of wood better for the mental health; Radon gas emissions. This is a gas which accumulates in closed environments and poses a danger to the human health and could be harmful for residents.

Although the above-mentioned effects could negatively impact the living environment of an apartment, these consequences are not fully taken into account in the Netherlands. Especially in current times with a housing shortage residents will rarely ask about the mental health in a house, especially not in the public sector(Interviewee 1, 2024). Now and then, villas built by private individuals will have designs where this is taken into account, but in the public sector this aspect is not expected to influence the demand for housing.

12. Conclusions & recommendations

In 2025 the maximum MPG-value for newly built real estate will be lowered by the Dutch government to contribute to reducing the negative impact on the environment. For residential buildings this value will go from 0.8 to 0.5 €/m2.year. For most of them this will be doable, but apartments buildings are expected to have difficulties with this tightened value, because of their height and their relatively big amount of walls and installations compared to the total GFA.

Multiple strategies to decrease the environmental impact of a building are possible; reusing or recycling materials, using biobased materials like wood, cork or straw or adjusting the form factors of the building. The case studies in this research showed that the main material used in the building influences the MPG-value the most, with wood as the favorable choice, which means using wood instead of concrete is the most effective adjustment that can be made. This is not only because of the fact that wood is a renewable material and therefore has a lower MKI than concrete, but it also requires a lighter foundation and it can store CO2, which is not fully included in the MPG-calculation method yet, so it can become even more beneficial in the future. Another positive effect of wood is the demountability, which is expected to be higher with wood than with concrete, although this is currently hard to reward in the MPG-calculation method yet. Because of the big influence of the main material, it is necessary to build with wood to meet the future required MPG-value of 0,5.

By taking the MPG-calculation into account from the beginning of the design phase, the adjustment of form factors can be used to decrease the MPG-value significantly. Decreasing the floor height to a minimum can lower the dimensions of the façade which saves material. Furthermore, the size of the apartment building, for example expressed in the number of apartments, the total GFA, and the size of the apartments, are preferred to be rather big than small. According to the case studies the total GFA should be more than 4000 m2. The importance of size is also shown when looking at the outline; the case studies with the best MPG-values had an average outline of almost 170 meters, while the worst scoring group only had 110 meters. Besides, by applying a square-shaped footprint the GFA/outline-ratio can be increased which is beneficial for the MPG too. Last but not least an internal circulation space instead of a gallery is favorable.

The prototype showed that taking these favorable choices into account, designing an apartment building with an MPG-value lower than 0.5 €/m2.y. is doable. Nevertheless the impact of the heat system is big and until 31st December 2024 a temporary multiplication factor for heat pumps with a power up to 4,0 kW is used. Without this factor heat pumps have such a high MKI that meeting an MPG-value of 0.5 is not possible, nevertheless from January 1st 2025 a new regulation regarding heat pumps will be introduced and it is expected that it still makes the required MPG possible to meet.

Using the strategies mentioned above will make it possible to meet an MPG-value of lower than 0,5. This research also studied the impact these strategies has on both the costs and the living environment. The use of innovative materials, like biobased materials will increase the costs at first, since these materials require research, have a smaller market and the manufacturers pass the costs of the risk on to the customer. However as soon as these markets grow and the required research is done, prices will decline. Furthermore there could be some point where the government will destimulate the use CO2-intensive materials by adding more tax, which could make biobased

materials even less expensive than traditional ones. Some of the strategies even lower the costs, because they are about decreasing the amount of materials needed, for example smaller floor heights or more efficient footprint shapes. A smaller volume also means less installations are needed.
The living environment in the apartment building is impacted by these strategies, both positively and negatively. First of all the use of biobased materials is expected to improve the human health of its residents, since some of them have a moisture-buffering capacity. Besides, the biophilic design principle states that natural materials improve both the mental and physical health of a human being. Negative sides of the strategies are the fact that a lower ceiling is often experienced as less comfortable and increasing the GFA could cause difficulties with the design of the floorplan regarding the amount of daylight.

13. Research limitations

In chapter 13 the main findings and results of this research are concluded. They give a good image of the answers to the research question. However, various sidenotes should be taken into account when reading these conclusions. During the research multiple limitations and obstacles crossed the way.

After the literature research a total of nine case studies were collected and compared. To do so, both the MPG-calculations and the construction drawings like floor plans and sections were needed. Unfortunately these are not freely available on the internet. Multiple companies were approached to receive these documents of projects concerning apartment buildings. For the number of apartments a range of 30-45 was set, although some case studies are just outside of it. In the end it would have been favorable to compare more than nine projects. When using big numbers, possible coincidenses are filtered(Interviewee 2, 2024).

Another limitation regarding the case studies concerns the amount of companies these projects were collected from. Case study 1 to 4 were all from the same company and the same goes for project 7 to 9. Because companies often standardize certain factors or materials, these case studies had a lot in common, for example the floor height or materials of the construction. Ideally the case studies were all built or developed by different companies.

Furthermore one factor that could influence the MPG-value is ignored in this research; the geographic context of projects. This could especially affect the foundation that is needed. A soil of sand is considered as the most stable for foundation, but other areas may contain peat, which requires a deeper foundation. The deeper there need to be digged the thicker the foundation poles need to be to prevent a kink(Interviewee 3, 2024). The foundation of the prototype is based on reference projects built on sand soil, so the foundation would probably have a higher MPG-value if it was built on a location with peat soil.

It was mentioned various times in this report; the lacking calculation method to determine the MPG-value. The MKI's of certain materials does not always correspond to reality, which makes the total values not completely reliable. Especially innovative materials that may score better than traditional materials are not always available in the MPG-tools. As mentioned in paragraph 8.8 the way of calculating the MPG could differ per person due to the lack of clear guidelines.

One of the main specific elements for which clear guidelines are missing is the heat pump, which was extensively discussed in chapter 10. This is also the reason why there were made two different versions of the MPG-calculation for the prototype. Among the case studies there are some projects both with a heat pump and without one. This makes the comparison a bit less reliable.

Another important sidenote to mention is the different NMD reference dates of the case studies. The MPG-value is based on the calculation of a certain date, but since the product cards of materials are constantly updated, these values can differ per day. In other words this means the MPG-value of project A on December 1st can be higher or lower than the MPG-value of project A on the December 15th. Interviewee 3(2024) also mentioned an example of a tender they won as their proposed plan had an MPG-value of 0,44 €/m2.y., but after making the same calculation 2 months later the MPG-value suddenly was 0,60 €/m2.y. When looking at the case studies in this report it should be taken into account that their MPG-calculations were not made on the same day, so their results would be different if calculated again today, although 7 out of 9 values were calculated in 2023 and most of the within a period of 6 months. The differences caused by the reference dates could have been much bigger if they were calculated in completely different years.

14. Future research

This research raises various ideas for future research. Multiple aspects of it could be studied further or more extensively. In this paragraph some of these ideas are shortly explained.

First of all this report mainly focused on the technical feasibility of apartment buildings meeting the future required MPG-value of 0.5. Based on literature and expectations from different experts possible consequences for the end-user were mentioned, however it did not involve potential end-users themselves. Future research could take a look into the demand for more sustainable apartments and for example test the impact of biobased materials on mental health, which was discussed in paragraph 8.7. For this report interviews were conducted among people working on the supply side of apartments, but the user-side could still be more elaborated on.

Paragraph 8.1 did already mention the change of future requirements for the MPG during the research. This report looked into the feasibility of apartment buildings with a value of 0.5 €/m2.year. However the A2-version will amount 1.0 €/m2.year for residential buildings and will have an exception for apartment buildings: 1.2 €/m2.year. It would be interesting to look into the feasibility of that value. The A2-change also contains different multiplication factors per material(figure 20), which is expected to be disadvantageous for wood for example. Will it then still be favorable to use wood for apartment buildings? Or will another material be more beneficial?

Last but not least it would be interesting to look into the feasibility of an apartment building meeting the required MPG-value, including the energy performance. This report does contain the design of a prototype meeting an MPG-value lower than 0.5, However it does not take the energy performance into account and therefore does not guarantee it is meeting the BENG-requirements. In the future it is expected that the energy performance and the environmental performance will be combined into one instrument: the MEPG(Gebouwd, 2023). Future research could study the feasibility using this future instrument.

15. Final reflection

15.1 Relation to the master track Management in the Built Environment

This report focuses on the so-called MPG-value, which stands for the Dutch words 'Milieu Prestatie Gebouw'(In English: Environmental Performance of Buildings). Since this is a scale that is mainly used in the Netherlands, this term is not translated in this report. This thesis is written within the theme **Sustainability transitions and the transformation of port cities.** The MPG is a method used in the Netherlands to decrease the environmental impact of our real estate. By tightening the maximum MPG-value of 0.8 to 0.5, the ambitions of the government to a more sustainable environment is strengthened. Since this will affect the way of designing and building real estate, this can be called a sustainability transition.

15.2 Methods

This study started with a literature review. Since the MPG is a term that is not often used within the MBE-track, the literature review was the introduction to this topic, so to speak. It provided the basic knowledge to start the research itself. Useful sources like the Lente-Akkoord 2.0 and various documents of W/E Adviseurs described the main ways to improve the MPG-value that were already available. Contractors and developers are stimulated to use these ways, however within the field of apartment buildings there are still many question marks about the actual feasibility of the new requirements.

The second part of the research contained interviews, case studies and the design of a prototype. Although collecting enough case studies turned out to be difficult in a world of companies that are not always willing to share their own methods, the nine collected case studies showed multiple lessons. In the end I would have preferred to have some more case studies, however I know this would have been difficult. The same goes for the diversity of the case studies.

By talking to people with different points of view on this topic, certain lessons were either confirmed or questioned. It were actually these confirmations or frictions that gave reason for discussion. This discussion was not only about whether a certain way of building improves the MPG or not, but it also exposed the lacks and limits of the current MPG-calculation method. Comparing MPG-calculations of different projects turned out to be more difficult than expected, because of the calculation method. This method is worth a research at itself. When looking back it is something to keep in mind that clear guidelines for making an MPG-calculation are missing, which means there could be mistakes in the calculations of the case studies. For that reason only the biggest differences were discussed in this report.

The interviews were done with three persons with different jobs and backgrounds. Since the MPG is a general instrument, it was really interesting and useful to get insights from different points of view. A lot of information gathered during these interviews overlapped, but some did not, which lead to new points of discussion.

The main findings of the case studies and interviews regarding the factors in a building that can influence the MPG were the basis for the prototype that was designed. How low can the MPG-value be for an apartment building? In the end this was not only a good method to actually test the technical feasibility, but by presenting it to a developer this exposed new potential problems regarding the practicality of the prototype. Although the prototype would initially be compared to an existing case study, this turned out to be difficult since the prototype was not worked out as detailed as the case study. Furthermore the prototype could have been discussed with multiple developers.

15.3 Academic & societal value

In the upcoming years a big part of the construction world needs to make a shift in their design phase, since the future MPG-requirements force them to already implement strategies to decrease the environmental impact of the building. This research shows the most influential factors of a building. It can help them meet the new required MPG-value of 0.5€/m2.year.

I think the main conclusions of this research regarding the most influential factors are useful, but the MPG-calculation is an instrument which is changing constantly. For example during my research the required MPG-value of 0.5 on which this research is focused on, was changed to 1.2. It was too late to change the research question, but the main question remained the same: how can the MPG-value be improved and meet the future requirements. In future research the improvement-strategies found by this research can be tested on the new required MPG-value of 1.2 for apartment buildings.

The information I gathered for the case studies were all confidential and could not be shared with third parties. However I am still positively surprised by the collaboration between different parties, which I especially noticed at the Lente-Akkoord and during my interview with Interviewee 2. The world of construction and real estate are really working together trying to make this new MPG-requirement possible and feasible.

Last but not least my research was less focused on the financial consequences of the improvement-strategies than expected. In figure 33 below the original conceptual model is shown, which has a more extensive upper side than the one in the end(figure 1). During the first interviews it turned out that the strategies to improve the MPG-value would not be that more expensive compared to the traditional way of building, which made it useless to check whether investors would still invest in more sustainable apartment buildings. Since multiple strategies were influencing the shape and size of the apartments, it was more interesting to look at developers and users. Therefore the investor's perspective was already dropped early in the process.

Note: This is an anonymized version of the thesis, which means confidential information like the names of the case studies, their drawings and the names of the interviewees were left out.

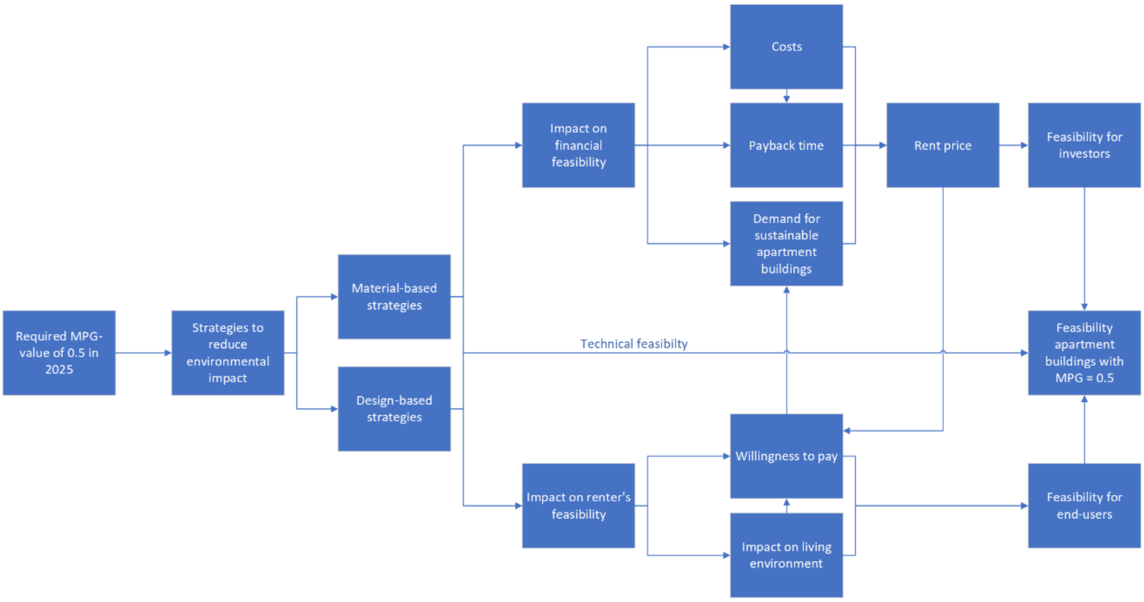

Figure 33: Original conceptual model(Own work, 2024)

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Appendix A: Data of case studies + prototype

MPG per fase	Casestudy 1	Casestudy 2	Casestudy 3	Casestudy 4	Casestudy 5	Casestudy 6	Casestudy 7	Casestudy 8	Casestudy 9	Prototype(V)	Prototype(NV)
Productiefase	0,421	0,61	0,421	0,396	0,273	0,181	0,352	0,4	0,365	0,225	0,258
Constructiefase	0,031	0,061	0,036	0,034	0,014	0,037	0,039	0,036	0,05	0,008	0,01
Gebruiksfase	0,297	0,165	0,115	0,114	0,251	0,132	0,188	0,101	0,063	0,238	0,404
Afdankfase	0,037	0,026	0,023	0,019	-0,018	0,09	0,057	0,026	0,041	-0,026	-0,026
Buiten gebouwlevensloop	-0,04	-0,075	-0,05	-0,045	-0,043	-0,068	-0,027	-0,043	-0,048	-0,018	-0,028

MPG per hoofdelement	Casestudy 1	Casestudy 2	Casestudy 3	Casestudy 4	Casestudy 5	Casestudy 6	Casestudy 7	Casestudy 8	Casestudy 9	Prototype 1(V)	Prototype 1(NV)
Fundering	0,075	0,029	0,037	0,01	0,02	0,014	0,048	0,086	0,041	0,008	0,008
Vloeren	0,122	0,208	0,141	0,142	0,054	0,045	0,154	0,159	0,184	0,052	0,052
Draagconstructie	0,004	0,139	0,095	0,099	0,032	0,024	0,02	0,021	0,044	0,004	0,004
Gevel	0,153	0,23	0,134	0,097	0,022	0,089	0,08	0,063	0,102	0,071	0,071
Daken	0,027	0,019	0,021	0,008	0,004	0,014	0,048	0,057	0,015	0,009	0,009
Binnenwanden	0,147	0,045	0,044	0,052	0,145	0,067	0,073	0,036	0,046	0,043	0,043
Klimaatinstallaties	0,077	0,034	0,035	0,039	0,043	0,061	0,106	0,025	0,015	0,083	0,277
Elektrische installaties	0,127	0,069	0,023	0,054	0,149	0,046	0,064	0,051	0,018	0,145	0,145
Toe-en afvoeren	0,002	0,002	0,001	0,002	0	0,002	0,002	0,002	0,002	0,003	0,003
Verkeersruimte	0,005	0,006	0,008	0,008	0,004	0,004	0,004	0	0,004	0,004	0,004
Vaste voorzieningen	0,005	0,006	0,005	0,006	0,001	0,005	0,011	0,019	0	0,005	0,005
Terrein	0	0	0	0	0	0	0	0	0	0	0
Totaal	**0,744**	**0,787**	**0,544**	**0,517**	**0,474**	**0,371**	**0,61**	**0,519**	**0,471**	**0,426**	**0,620**

Form factors	Casestudy 1	Casestudy 2	Casestudy 3	Casestudy 4	Casestudy 5	Casestudy 6	Casestudy 7	Casestudy 8	Casestudy 9	Prototype 1(V)	Prototype 1(NV)
GFA in m2	3459	2581	4689	9095	5984	3225	3980	2242,3	4338,1	4598,12	4598,12
Aantal appartementen	34	30	47	106	56	29	39	22	40	40	40
m2/appartement(verkeersruimte meegerekend)	101,74	86,03	99,77	85,80	106,86	111,21	102,05	101,92	108,45	114,95	114,95
Verdiepingshoogte in m	3,008	3,008	3,008	3,008	3,145	3,000	3,000	3,000	3,000	2,9	2,9
Omtrek	105,268	113,852	109,22	105,27	228	117,89	184,34	143,64	157,276	129,6	129,6
Footprint gemid. Verdieping	683,86	485,31	683,34	624,05	1397,71	710,95	1072,24	748,9	779,8	1149,53	1149,53
GFA/omtrek	6,496	4,263	6,257	5,928	6,130	6,031	5,817	5,214	4,958	8,870	8,870
Bouwlagen	5	6	7	13	5	5	4	3	4	4	4
Verkeersruimte in m2(collectief)	88,09	82,47	94,95	88,09	204,0897	93,85	140,5	90,8	98,9	99,02	99,02
%verkeersruimte tov BVO gemid. Verdieping	12,88%	16,99%	13,89%	14,12%	14,60%	13,20%	13,10%	12,12%	12,68%	8,61%	8,61%
m2 buitenruimte(excl tuin)	58,44	122,87	51,7	82	86,8	63,6	133,12	101,7	129	99,78	99,78
%buitenruimte tov BVO(gemid. Verd)	8,55%	25,32%	7,57%	13,14%	6,21%	8,95%	12,42%	13,58%	16,54%	8,68%	8,68%
Galerij?	Nee	Ja	Nee	Nee	Nee	Nee	Ja	Ja	Ja	nee	nee

Appendix B: T-Tests

Main material

	Mean: Wood	Concrete		Difference	% of gr. 1	% of total mean MPG
Production phase	0,227	0,424		-0,197	-86,60%	-35,21%
Construction phase	0,026	0,041		-0,016	-60,78%	-2,78%
Use phase	0,192	0,149		0,043	22,19%	7,61%
Disposal phase	0,036	0,033		0,003	9,13%	0,59%
Ouside building lifecycle	-0,056	-0,047		-0,009	15,57%	-1,55%
Foundation	0,017	0,047		-0,030	-173,95%	-5,30%
Floors	0,050	0,159		-0,109	-220,35%	-19,54%
Construction	0,028	0,060		-0,032	-115,31%	-5,78%
Façade	0,056	0,123		-0,067	-121,11%	-12,04%
Roof	0,009	0,028		-0,019	-209,52%	-3,38%
Interior walls	0,106	0,063		0,043	40,30%	7,65%
Climate installations	0,052	0,047		0,005	9,07%	0,84%
Electrical installations	0,098	0,058		0,040	40,51%	7,07%
Supply and exhaust	0,001	0,002		-0,001	-85,71%	-0,15%
Circulation space	0,004	0,005		-0,001	-25,00%	-0,18%
Fixed facilities	0,003	0,007		-0,004	-147,62%	-0,79%
Terrain	0,000	0,000		0,000		0
Total mean	0,425	0,597		-0,172	-40,54%	-30,82%
Mean mpg	**0,5583333**					

Group 1: Wood	Group 2: Concrete
Casestudy 5	Casestudy 1
Casestudy 6	Casestudy 2
	Casestudy 3
	Casestudy 4
	Casestudy 7
	Casestudy 8
	Casestudy 9

Size of apartments

	Mean: <95 m2	>95 m2		Difference	% of gr. 1	% of total mean MPG
Production phase	0,44275	0,3296		0,11315	25,56%	20,27%
Construction phase	0,04525	0,0314		0,01385	30,61%	2,48%
Use phase	0,11075	0,1966		-0,08585	-77,52%	-15,38%
Disposal phase	0,028	0,0378		-0,0098	-35,00%	-1,76%
Ouside building lifecycle	-0,05275	-0,0456		-0,00715	13,55%	-1,28%
Foundation	0,0415	0,0388		0,0027	6,51%	0,48%
Floors	0,17325	0,1032		0,07005	40,43%	12,55%
Construction	0,07575	0,035		0,04075	53,80%	7,30%
Façade	0,123	0,0956		0,0274	22,28%	4,91%
Roof	0,02475	0,0228		0,00195	7,88%	0,35%
Interior walls	0,04475	0,0952		-0,05045	-112,74%	-9,04%
Climate installations	0,02825	0,0644		-0,03615	-127,96%	-6,47%
Electrical installations	0,048	0,0818		-0,0338	-70,42%	-6,05%
Supply and exhaust	0,002	0,0014		0,0006	30,00%	0,11%
Circulation space	0,0045	0,005		-0,0005	-11,11%	-0,09%
Fixed facilities	0,00775	0,0054		0,00235	30,32%	0,42%
Terrain	0	0		0		
Total mean	0,56925	0,5496		0,01965	3,45%	3,52%
Mean mpg	**0,558333**					

Group 1: <95 m2	Group 2: >95 m2
Casestudy 2	Casestudy 1
Casestudy 4	Casestudy 3
Casestudy 8	Casestudy 5
Casestudy 9	Casestudy 6
	Casestudy 7

Number of apartments

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: <35	Group 2: >35
	< 35	>35							
Production phase	0,403	0,3614		0,0416	10,32%	7,45%		Casestudy 1	Casestudy 3
Construction phase	0,04125	0,0346		0,00665	16,12%	1,19%		Casestudy 2	Casestudy 4
Use phase	0,17375	0,1462		0,02755	15,86%	4,93%		Casestudy 6	Casestudy 5
Disposal phase	0,04475	0,0244		0,02035	45,47%	3,64%		Casestudy 8	Casestudy 7
Ouside building lifecycle	-0,0565	-0,0426		-0,0139	24,60%	-2,49%			Casestudy 9
Foundation	0,051	0,0312		0,0198	38,82%	3,55%			
Floors	0,1335	0,135		-0,0015	-1,12%	-0,27%			
Construction	0,047	0,058		-0,011	-23,40%	-1,97%			
Façade	0,13375	0,087		0,04675	34,95%	8,37%			
Roof	0,02925	0,0192		0,01005	34,36%	1,80%			
Interior walls	0,07375	0,072		0,00175	2,37%	0,31%			
Climate installations	0,04925	0,0476		0,00165	3,35%	0,30%			
Electrical installations	0,07325	0,0616		0,01165	15,90%	2,09%			
Supply and exhaust	0,002	0,0014		0,0006	30,00%	0,11%			
Circulation space	0,00375	0,0056		-0,00185	-49,33%	-0,33%			
Fixed facilities	0,00875	0,0046		0,00415	47,43%	0,74%			
Terrain	0	0		0		0			
Total mean	0,60175	0,5236		0,07815	12,99%	14,00%			
Mean mpg	0,558333								

Gross Floor Area

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: <4000 m2	Group 2: >4000 m2
	< 4000 m2	>4000 m2							
Production phase	0,388	0,363		0,025	6,40%	4,45%		Casestudy 1	Casestudy 3
Construction phase	0,042	0,028		0,014	33,86%	2,57%		Casestudy 2	Casestudy 4
Use phase	0,158	0,160		-0,002	-1,48%	-0,42%		Casestudy 6	Casestudy 5
Disposal phase	0,046	0,008		0,038	82,67%	6,84%		Casestudy 7	
Ouside building lifecycle	-0,050	-0,046		-0,004	8,31%	-0,75%		Casestudy 8	
								Casestudy 9	
Foundation	0,049	0,022		0,027	54,27%	4,75%			
Floors	0,145	0,112		0,033	22,71%	5,91%			
Construction	0,042	0,075		-0,033	-79,37%	-5,97%			
Façade	0,120	0,084		0,035	29,43%	6,30%			
Roof	0,030	0,011		0,019	63,33%	3,40%			
Interior walls	0,069	0,080		-0,011	-16,43%	-2,03%			
Climate installations	0,053	0,039		0,014	26,42%	2,51%			
Electrical installations	0,063	0,075		-0,013	-20,53%	-2,30%			
Supply and exhaust	0,002	0,001		0,001	50,00%	0,18%			
Circulation space	0,004	0,007		-0,003	-73,91%	-0,51%			
Fixed facilities	0,008	0,004		0,004	47,83%	0,66%			
Terrain	0	0		0,000		0,00%			
Total mean	0,581	0,513		0,068	11,70%	12,18%			
Mean mpg	0,55833333								

Amount of circulation space %

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: < 13,5%	Group 2: >13,5 %
	Group 1: < 13,5%	Group 2: >13,5 %							
Production phase	0,387	0,371		0,016	4,02%	2,79%		Casestudy 1	Casestudy 2
Construction phase	0,038	0,037		0,001	2,63%	0,18%		Casestudy 4	Casestudy 3
Use phase	0,153	0,166		-0,013	-8,62%	-2,36%		Casestudy 7	Casestudy 5
Disposal phase	0,036	0,030		0,006	15,97%	1,03%		Casestudy 8	Casestudy 6
Ouside building lifecycle	-0,041	-0,059		0,018	-45,32%	3,30%		Casestudy 9	
Foundation	0,052	0,025		0,027	51,92%	4,84%			
Floors	0,152	0,112		0,040	26,41%	7,20%			
Construction	0,038	0,073		-0,035	-92,82%	-6,25%			
Façade	0,099	0,119		-0,020	-19,95%	-3,54%			
Roof	0,031	0,015		0,017	53,23%	2,96%			
Interior walls	0,071	0,075		-0,004	-6,29%	-0,80%			
Climate installations	0,052	0,043		0,009	17,46%	1,64%			
Electrical installations	0,063	0,072		-0,009	-14,25%	-1,60%			
Supply and exhaust	0,002	0,001		0,001	37,50%	0,13%			
Circulation space	0,004	0,006		-0,001	-30,95%	-0,23%			
Fixed facilities	0,008	0,004		0,004	48,17%	0,71%			
Terrain	0,000	0,000		0,000		0,00%			
Total mean	0,5724	0,54075		0,03165	5,53%	5,67%			
Mean mpg	0,558333333								

Amount of outdoor space %

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: < 10%	Group 2: >10 %
	Group 1: < 10%	Group 2: >10 %							
Production phase	0,324	0,384		-0,060	-18,52%	-10,75%		Casestudy 1	Casestudy 2
Construction phase	0,030	0,043		-0,013	-45,20%	-2,39%		Casestudy 3	Casestudy 4
Use phase	0,199	0,127		0,072	36,02%	12,82%		Casestudy 5	Casestudy 6
Disposal phase	0,033	0,043		-0,010	-30,81%	-1,82%		Casestudy 6	Casestudy 7
Ouside building lifecycle	-0,050	-0,051		0,001	-1,49%	0,13%			Casestudy 8
									Casestudy 9
Foundation	0,037	0,038		-0,002	-4,11%	-0,27%			
Floors	0,091	0,149		-0,058	-64,27%	-10,42%			
Construction	0,039	0,058		-0,019	-49,25%	-3,42%			
Façade	0,100	0,110		-0,011	-10,72%	-1,91%			
Roof	0,017	0,027		-0,010	-62,63%	-1,85%			
Interior walls	0,101	0,053		0,048	47,23%	8,52%			
Climate installations	0,054	0,047		0,007	13,58%	1,31%			
Electrical installations	0,086	0,050		0,036	41,64%	6,43%			
Supply and exhaust	0,001	0,002		-0,001	-60,00%	-0,13%			
Circulation space	0,005	0,004		0,001	17,46%	0,16%			
Fixed facilities	0,004	0,008		-0,004	-95,83%	-0,69%			
Terrain	0,000	0,000		0,000		0,00%			
Total mean	0,535	0,542833333		-0,0078333	-1,46%	-1,40%			
Mean mpg	0,558333333								

GFA/Outline-ratio

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: < 5,3	Group 2: >5,3
	Group 1: < 5,3	Group 2: >5,3							
Production phase	0,458	0,341		0,118	25,67%	21,07%		Casestudy 2	Casestudy 1
Construction phase	0,049	0,032		0,017	35,03%	3,07%		Casestudy 8	Casestudy 3
Use phase	0,110	0,183		-0,073	-66,72%	-13,10%		Casestudy 9	Casestudy 4
Disposal phase	0,031	0,035		-0,004	-11,83%	-0,66%			Casestudy 5
Ouside building lifecycle	-0,055	-0,046		-0,010	17,77%	-1,76%			Casestudy 6
									Casestudy 7
Foundation	0,052	0,034		0,018	34,62%	3,22%			
Floors	0,184	0,110		0,074	40,29%	13,25%			
Construction	0,068	0,046		0,022	32,84%	4,00%			
Façade	0,132	0,096		0,036	27,22%	6,42%			
Roof	0,030	0,020		0,010	32,97%	1,79%			
Interior walls	0,042	0,088		-0,046	-107,87%	-8,18%			
Climate installations	0,025	0,060		-0,036	-143,92%	-6,36%			
Electrical installations	0,046	0,077		-0,031	-67,75%	-5,58%			
Supply and exhaust	0,002	0,002		0,001	25,00%	0,09%			
Circulation space	0,003	0,006		-0,002	-65,00%	-0,39%			
Fixed facilities	0,008	0,006		0,003	34,00%	0,51%			
Terrain	0,000	0,000		0,000		0,00%			
Total mean	0,586666667	0,544166667		0,0425	7,24%	7,61%			
Mean mpg	0,558333333								

Gallery?

	Mean			Difference	% of gr. 1	% of total mean MPG		Group 1: Yes	Group 2: No
	Group 1: Ja	Group 2: >Nee							
Production phase	0,432	0,338		0,093	21,62%	16,72%		Casestudy 2	Casestudy 1
Construction phase	0,047	0,030		0,016	34,62%	2,88%		Casestudy 7	Casestudy 3
Use phase	0,129	0,182		-0,053	-40,66%	-9,41%		Casestudy 8	Casestudy 4
Disposal phase	0,038	0,030		0,007	19,47%	1,31%		Casestudy 9	Casestudy 5
Ouside building lifecycle	-0,048	-0,049		0,001	-1,97%	0,17%			Casestudy 6
Foundation	0,051	0,031		0,020	38,82%	3,55%			
Floors	0,176	0,101		0,075	42,81%	13,51%			
Construction	0,056	0,051		0,005	9,29%	0,93%			
Façade	0,119	0,099		0,020	16,63%	3,54%			
Roof	0,035	0,015		0,020	57,41%	3,57%			
Interior walls	0,050	0,091		-0,041	-82,00%	-7,34%			
Climate installations	0,045	0,051		-0,006	-13,33%	-1,07%			
Electrical installations	0,051	0,080		-0,029	-58,02%	-5,25%			
Supply and exhaust	0,002	0,001		0,001	30,00%	0,11%			
Circulation space	0,004	0,006		-0,002	-65,71%	-0,41%			
Fixed facilities	0,009	0,004		0,005	51,11%	0,82%			
Terrain	0,000	0,000		0,000		0,00%			
Total mean	0,592	0,5314		0,0606	10,24%	10,85%			
Mean mpg	0,558333333								

Floor height

	Mean			Difference	% of gr. 1	% of total mean MPG
	Group 1: <3 m	Group 2: >3m				
Production phase	0,325	0,424		-0,100	-30,72%	-17,86%
Construction phase	0,041	0,035		0,005	13,09%	0,95%
Use phase	0,121	0,188		-0,067	-55,70%	-12,07%
Disposal phase	0,054	0,017		0,036	67,48%	6,47%
Ouside building lifecycle	-0,047	-0,051		0,004	-8,82%	0,73%
Foundation	0,047	0,034		0,013	27,62%	2,34%
Floors	0,136	0,133		0,002	1,55%	0,38%
Construction	0,027	0,074		-0,047	-170,83%	-8,34%
Façade	0,084	0,127		-0,044	-52,34%	-7,83%
Roof	0,034	0,016		0,018	52,84%	3,17%
Interior walls	0,056	0,087		-0,031	-56,04%	-5,57%
Climate installations	0,052	0,046		0,006	11,88%	1,10%
Electrical installations	0,045	0,084		-0,040	-88,60%	-7,10%
Supply and exhaust	0,002	0,001		0,001	30,00%	0,11%
Circulation space	0,003	0,006		-0,003	-106,67%	-0,57%
Fixed facilities	0,009	0,005		0,004	47,43%	0,74%
Terrain	0,000	0,000		0,000		0,00%
Total mean	0,49275	0,6108		-0,11805	-23,96%	-21,14%
Mean mpg	**0,558333333**					

Group 1: <3m	Group 2: >3m
Casestudy 6	Casestudy 1
Casestudy 7	Casestudy 2
Casestudy 8	Casestudy 3
Casestudy 9	Casestudy 4
	Casestudy 5

Appendix C: Analysis of variance

	Mean								
	Group 1: < 0,5	Group 2: 0,5 - 0,7	Group 3: > 0,7	Difference 1-2	% of total mpg	Difference 2-3	% of total mpg	Difference 1-3	% of total mpg
Production phase	0,273	0,392	0,516	-0,119	-21,36%	-0,123	-22,07%	-0,243	-43,43%
Construction phase	0,034	0,036	0,046	-0,003	-0,46%	-0,010	-1,75%	-0,012	-2,21%
Use phase	0,149	0,130	0,231	0,019	3,43%	-0,102	-18,18%	-0,082	-14,75%
Disposal phase	0,038	0,031	0,032	0,006	1,15%	0,000	-0,04%	0,006	1,10%
Ouside building lifecycle	-0,053	-0,041	-0,058	-0,012	-2,10%	0,016	2,91%	0,005	0,81%
Foundation	0,025	0,045	0,052	-0,020	-3,63%	-0,007	-1,21%	-0,027	-4,84%
Floors	0,094	0,149	0,165	-0,055	-9,79%	-0,016	-2,87%	-0,071	-12,66%
Construction	0,033	0,059	0,072	-0,025	-4,55%	-0,013	-2,28%	-0,038	-6,84%
Façade	0,071	0,094	0,192	-0,023	-4,03%	-0,098	-17,55%	-0,121	-21,58%
Roof	0,011	0,034	0,023	-0,023	-4,03%	0,011	1,88%	-0,012	-2,15%
Interior walls	0,086	0,051	0,096	0,035	6,22%	-0,045	-8,01%	-0,010	-1,79%
Climate installations	0,040	0,051	0,056	-0,012	-2,07%	-0,004	-0,76%	-0,016	-2,84%
Electrical installations	0,071	0,048	0,098	0,023	4,12%	-0,050	-8,96%	-0,027	-4,84%
Supply and exhaust	0,001	0,002	0,002	0,000	-0,07%	0,000	-0,04%	-0,001	-0,12%
Circulation space	0,004	0,005	0,006	-0,001	-0,18%	-0,001	-0,09%	-0,002	-0,27%
Fixed facilities	0,002	0,010	0,006	-0,008	-1,48%	0,005	0,85%	-0,004	-0,63%
Terrain	0,000	0,000	0,000	0,000	0,00%	0,000	0,00%	0,000	0,00%
Total mean	0,440	0,548	0,758	-0,108		-0,210		-0,318	
Mean mpg	**0,558333333**								

Group 1: < 0,5	Group 2: 0,5 - 0,7	Group 3: > 0,7
Casestudy 5	Casestudy 3	Casestudy 1
Casestudy 6	Casestudy 4	Casestudy 2
Casestudy 9	Casestudy 7	
	Casestudy 8	

Form factors			
GFA in m2	4515,700	5001,575	3020
Aantal appartementen	41,667	53,5	32
m2/appartement	108,839	97,38546339	93,88431373
Verdiepingshoogte in m	3,048	3,004	3,008
Omtrek	167,722	135,6175	109,56
Footprint gemid. Verdieping	962,820	782,1325	584,585
GFA/omtrek	5,706	5,803752005	5,379505191
Bouwlagen	4,667	6,75	5,5
Verkeersruimte in m2(collectie	132,280	103,585	85,28
%verkeersruimte tov BVO gem	13,50%	13,31%	14,94%
m2 buitenruimte(excl tuin)	93,133	92,13	90,655
%buitenruimte tov BVO(gemid	10,57%	11,68%	16,93%

Appendix D: Prototype

GPR materiaal

Rapportage Milieuprestatieberekening

Naam berekening: Prototype 1

Projectkenmerken

Projectlocatie

ADRES

POSTCODE

PLAATS

Projectorganisatie

CLIËNT

ARCHITECT

DATUM VERGUNNINGSAANVRAAG

Gebouwkenmerken

Gebouw

GEBRUIKSFUNCTIE
Woonfunctie

BRUTO VLOEROPPERVLAK (BVO)
4598.12 m^2

GEBRUIKSOPPERVLAKTE (GBO)
4200

GEBOUWLEVENSDUUR
75 jaar

Verantwoording

Deze berekening is gemaakt met GPR Materiaal versie 5. Er is voor de berekening gebruik gemaakt van de productendatabase met peildatum 16 mei 2024 van de nationale milieudatabase versie 3.0

MPG Resultaten

MPG

Berekend per m2 BVO, per jaar

0,421

A. Productiefase	0,210
A. Constructiefase	0,008
B. Gebruiksfase	0,246
C. Afdankfase	-0,027
D. Buiten gebouwlevensloop	-0,017

MKI

Berekend over de totale BVO en levensduur

145.052

A. Productiefase	72.262,310
A. Constructiefase	2.833,884
B. Gebruiksfase	84.941,356
C. Afdankfase	-9.258,286
D. Buiten gebouwlevensloop	-5.727,248

Paris Proof Indicator (materiaalgebonden emissies)

Embodied carbon in kg CO2 eq, per m2 BVO

134

GWP Voor EU Taxonomy

Embodied carbon in kg CO2 eq, per m2 GBO, per jaar

3,114

A. Productiefase	2,807
A. Constructiefase	0,118
B. Gebruiksfase	1,238
C. Afdankfase	-0,723
D. Buiten gebouwlevensloop	-0,326

Resultaat voor overnemen in GPR Gebouw 4.3

Klimaatverandering - GWP 100 jaar

Berekend in kg CO2 eq, per m2 BVO, per jaar

2,645

Resultaat voor overnemen in GPR Gebouw 4.4

Klimaatverandering - GWP 100 jaar

Berekend in kg CO2 eq, per jaar

12.162,894

MPG Resultaten Per Hoofdelement

MPG 0,421

Fundering	0,008	2 %	Vloeren	0,052	12 %
Draagconstructie	0,004	1 %	Gevel	0,055	13 %
Daken	0,009	2 %	Binnenwanden	0,043	10 %
Klimaatinstallaties	0,094	22 %	Elektrische installaties	0,145	34 %
Toe- en afvoeren	0,003	1 %	Verkeersruimte	0,004	1 %
Vaste voorzieningen	0,005	1 %	Terrein	0,000	0 %

Elementen

Funderingsbalken 0,007

Funderingsconstructies; voetenenbalken

Cat. 2 Fundatiebalken, Betonhuis; beton,in het werk gestort, C3037,CEMIII; incl.wapening+eps 370 m 0,007

Funderingspalen 0,001

Paalfunderingen; geheid

Cat. 2 Heipaal, beton, prefab, 250×250 mm, Betonhuis breedte 0.25 m breedte 0.25 m 68,92 m 0,001

Bodemvoorzieningen 0,000

Bodemvoorzieningen; grond

Cat. 3 Grondaanvullingen, Zand 220 m^3 0,000

dikte 20 cm x 1100m² = 220m³

Verdiepingsvloeren 0,031

Vloeren; constructief

Cat. 3 Vrijdragende Vloeren, HSB; Europees naaldhout balken, steenwol, multiplex, 2x gipsplaat; duurzame bosbouw dikte 338 mm 3.448,59 m^2 0,028

Plafondafwerkingen; verlaagd

Cat. 3 Afwerklagen, Spuitpleister dikte 3 mm 3.448,59 m^2 0,003

Vrijdragende vloeren 0,017

Vloeren; constructief

Cat. 3 Vrijdragende Vloeren, Houten kanaalplaatvloer dikte 338 mm 1.149,53 m^2 0,015

Vloerafwerkingen; nietverhoogd

Cat. 3 Bekledingen, Europees naaldhout; duurzame bosbouw dikte 12 mm hoogte 55 mm 4.230,27 m 0,001

Wat is dit? is dit het aantal meters aan bekleding op de vloer?

Cat. 1 Isolatielagen vloer, Knauf Insulation Naturoll 037 rwaarde 3.7 1.149,53 m^2 0,001

biobased isolatie geselecteerd. scoort beter

Vloeren, balkon en galerij 0,004

Vloeren; niet-constructief

Cat. 3 Vrijdragende Vloeren, Massief houtenvloer dikte 201 mm 300 m^2 0,004

GPR materiaal

Kolommen en liggers

0,004

Hoofddraagconstructies; kolommenenliggers

Cat. 3	Kolommen, Gelamineerd europees naaldhout; duurzame bosbouw	dikte 220 mm diepte 300 mm	894,6 m	0,004

Gevels, dicht

0,005

Buitenwanden; niet-constructief

Cat. 3	Systeemwanden, HSB element; Europees naaldhouten multiplex en gipsplaat; duurzame bosbouw	dikte 160 mm	560 m^2	0,002
Cat. 3	Isolatielagen, EPS	r-waarde 4.7 m2k/w	560 m^2	0,003

van 3,70 naar 4,70 conform Bbl

Binnenwandafwerkingen

Cat. 2	Houten planken van Europees zachthout vuren of grenen met mes en groef uit hergebruik handmatig geoogst door VERAS3		560 m^2	0,000

Gevels, open

0,050

Buitenwandopeningen; gevuld met ramen

Cat. 3	Buitenbeglazing, Drievoudig glas; droog beglaasd (Hergebruikt)	dikte 12	891,52 m^2	0,047
Cat. 3	Waterslagen, Beton	breedte 165 mm hoogte 58 mm	405,32 m	0,001
Cat. 3	Waterkeringen, EPDM; folie	dikte 50 mm dikte 1 mm	891,52 m	0,001
Cat. 3	Buitenkozijnen, Europees naaldhout; geschilderd, acryl; duurzame bosbouw		445,26 m^2	0,001

Plat dak

0,009

Dakafwerkingen; bekledingen

Cat. 2	Plat dakbedekking, Stg. Dak en Milieu, Bitumen gemod. tweelaags 6,6 mm, 8,1 kg per m2, losliggend incl. ballast system 07, incl. 1x overlagen		1.077,15 m^2	0,006

deze staat er 2x in, 1 verwijderd.

Daken; constructief

Cat. 1	Isolatielagen dak constructief, Knauf Insulation Naturoll 035	rwaarde 6.3	1.077,15 m^2	0,002

Rc = 6,30 conform Bbl + biobased variant geselecteerd

Daken; niet-constructief

Cat. 3	Dak niet constructief, gootconstructie en dakranden, PVC		126,5 m^2	0,000

dakrand 126,5m

EPDM folie

0,000

Dakafwerkingen; afwerkingen

Cat. 3	Waterkeringen, EPDM aluminium versterkt	breedte 300 mm dikte 2.3 mm	126,5 m	0,000

dakrand ingeschat op 126,50m

Binnenwand openingen

0,011

Binnenwandopeningen; gevuldmetdeuren

Cat. 3	Binnendorpels, Kunststeen	hoogte 20 mm	160 m	0,002
Cat. 3	Binnenkozijnen, Staal; verzinkt+gemoffeld		396 m^2	0,004
Cat. 3	Binnendeuren, Honingraat; geschilderd:alkyd		160 st	0,005

Binnenwanden, niet-constructief-gemeenschappelijk

0,027

Binnenwanden; niet-constructief

Cat. 3	Systeemwanden niet dragend verplaatsbaar, Staalframe element; spaanplaat paneel; duurzame bosbouw		1.466,08 m^2	0,025
Cat. 3	Afwerklagen, Spuitpleister	dikte 3 mm	1.466,08 m^2	0,001

Binnenwanden, niet-constructief-woningen

0,004

Binnenwanden; niet-constructief

Cat. 3	Systeemwanden niet dragend bevestigingsprofielen, Europees naaldhout profiel	dikte 46 mm breedte 71 mm	2.191 m	0,000
Cat. 3	Afwerklagen, Keramische tegels; geglazuurd/gelijmd		501 m^2	0,003
Cat. 3	Afwerklagen, Spuitpleister	dikte 3 mm	1.690 m^2	0,002

Warmteopwekking

0,018

Warmte opwekking; hoofverdelingwarmte

Cat. 3	Warmtedistributiesystemen, Polyetheen/polybuteen; cv-leidingen; incl. koppelingen + verdeling	4.200 m^2gbo	0,011

Warmtedistributie; verwarmingslichamen

Cat. 3	Warmteafgiftesystemen, Vloerverwarming 95 Wm2; leidingen:kunststof	4.200 m^2gbo	0,007

Luchtbehandeling

0,032

Luchtbehandeling; luchtbehandelingskasten

Cat. 3	Luchtdistributiesystemen, Luchtbehandelingskast; mechanische ventilatie	4.200 m^2gbo	0,015

Luchtbehandeling; lokale(dak)ventilatoren

Cat. 3	Luchtdistributiesystemen, WTW-unit	4.200 m^2gbo	0,002

Luchtbehandeling; kanaalwerk

Cat. 3	Luchtdistributiesystemen, Ventilatiekanalen	4.200 m^2gbo	0,015

Verwarming 0,031

Warmtedistributie; verwarmingslichamen

Cat. 3	Warmteafgiftesystemen, Vloerverwarming; leidingen:polybuteen+toebehoren	4.200 m^2gbo	0,015

Warmte opwekking; bijzonder

Cat. 3	Luchtwater warmtepomp, split unit, R134a, stuks 3 tm 4 kWt, VERREKEND	vermogen 4 vermogen 4	40 stuk(s)	0,015

in plaats van ventilatieretourluchtwartempomp

Koeling 0,013

Koude-opwekking; centraal

Cat. 3	Koudeopwekkingsinstallaties, Compressiekoelmachine	4.200 m^2gbo	0,013

Elektrische installaties 0,145

Beveiliging: Aarding en bliksembeveiliging

Cat. 3	Aarding, aarding woningen	4.200 m^2gbo	0,005

Centrale elektrotechnische voorzieningen; energiedistributie, laagspanning,

Cat. 3	Elektricteitsleidingen, Geisoleerde installatiedraad + mantelbuis:pvc	4.200 m^2gbo	0,004

Centrale elektrotechnische voorzieningen; energie, opwekking

Cat. 3a	Centrale elektrotechnische voorz.; energie, laagspanning, algemeen, Netstroom; NL-mix, 1 kWh (forfaitair)	92.000 kWh	0,061

Gemiddeld verbruik appartement = 2300kWh/J x 40 app = 92.200 kWh/j

Cat. 3	Elektriciteitsopwekkingsystemen, PV,mono-Si; plat dak; incl. inverter+steun+kabels	152 m^2	0,075

1 paneel = 1,90m² * 80 stuks (2 per app) = 152m² (dit is een inschatting, aangezien we geen BENG berekening hebben)

Tapwater 0,000

Water; drinkwater

Cat. 3	Waterleidingen, Polyetheen; leiding+mantelbuis	4.200 m^2gbo	0,000

Afvoeren 0,003

Afvoeren; regenwater

Cat. 3	Binnenrioleringen, Pvc; gerecycled; leiding	4.200 m^2gbo	0,002
Cat. 3	Buitenrioleringen kavel, Pvc; gerecycled; leiding	4.200 m^2gbo	0,001
Cat. 3	Hemelwaterafvoeren, Pvc; grecycled; diameter:80mm; d:1.8mm	250 m	0,000

GPR materiaal

Trappen
0,002

Trappenenhellingen; trappen

Cat. 3	Interne trappen, Europees loofhout; geschilderd, acryl; duurzame bosbouw	4 st	0,000

1 centrale trap

Balustradesenleuningen; balustrades

Cat. 3	Balustrades, Europees loofhout; spijlen; duurzame bosbouw	600 m	0,002

Balustradesenleuningen; leuningen

Cat. 3	Leuningen, Europees loofhout; duurzame bosbouw	100 m	0,000

Liften
0,002

Transport; liften

Cat. 3	Liftinstallaties, Staal; hefconstructie+contragewicht; 1 bouwlaag	4 st	0,001

4 bouwlagen

Cat. 3	Liftcabines, Staal; personenlift; gemoffeld	1 st	0,000

1 lift

Vaste voorzieningen
0,005

Vastesanitairevoorzieningen; standaard

Cat. 3	Toiletten, Wandcloset + fontein, porselein; incl. kunststof reservoir	40 st	0,001
Cat. 3	Wasvoorzieningen, Keramiek; wastafel	40 st	0,000
Cat. 3	Douchevoorzieningen, Inloopdouche, gipsblokken+tegels; incl. rvs afvoergoot	40 st	0,004

GPR materiaal

Rapportage Milieuprestatieberekening

Naam berekening: Prototype 1 - niet verrekende WP

Projectkenmerken

Projectlocatie

ADRES

POSTCODE

PLAATS

Projectorganisatie

CLIËNT

ARCHITECT

DATUM VERGUNNINGSAANVRAAG

Gebouwkenmerken

Gebouw

GEBRUIKSFUNCTIE
Woonfunctie

BRUTO VLOEROPPERVLAK (BVO)
4598.12 m^2

GEBRUIKSOPPERVLAKTE (GBO)
4200

GEBOUWLEVENSDUUR
75 jaar

Verantwoording

Deze berekening is gemaakt met GPR Materiaal versie 5. Er is voor de berekening gebruik gemaakt van de productendatabase met peildatum 16 mei 2024 van de nationale milieudatabase versie 3.0

MPG Resultaten

MPG

Berekend per m2 BVO, per jaar

0,630

A. Productiefase	0,261
A. Constructiefase	0,010
B. Gebruiksfase	0,413
C. Afdankfase	-0,025
D. Buiten gebouwlevensloop	-0,029

MKI

Berekend over de totale BVO en levensduur

217.233

A. Productiefase	90.037,112
A. Constructiefase	3.460,459
B. Gebruiksfase	142.318,863
C. Afdankfase	-8.612,376
D. Buiten gebouwlevensloop	-9.971,161

Paris Proof Indicator (materiaalgebonden emissies)

Embodied carbon in kg CO2 eq, per m2 BVO

154

GWP Voor EU Taxonomy

Embodied carbon in kg CO2 eq, per m2 GBO, per jaar

5,421

A. Productiefase	3,226
A. Constructiefase	0,151
B. Gebruiksfase	3,128
C. Afdankfase	-0,679
D. Buiten gebouwlevensloop	-0,405

Resultaat voor overnemen in GPR Gebouw 4.3

Klimaatverandering - GWP 100 jaar

Berekend in kg CO2 eq, per m2 BVO, per jaar

4,706

Resultaat voor overnemen in GPR Gebouw 4.4

Klimaatverandering - GWP 100 jaar

Berekend in kg CO2 eq, per jaar

21.638,274

MPG Resultaten Per Hoofdelement

MPG 0,630

●	Fundering	0,008	1 %	●	Vloeren	0,052	8 %
●	Draagconstructie	0,004	1 %	●	Gevel	0,071	11 %
●	Daken	0,009	1 %	●	Binnenwanden	0,043	7 %
●	Klimaatinstallaties	0,287	46 %	●	Elektrische installaties	0,145	23 %
●	Toe- en afvoeren	0,003	0 %	●	Verkeersruimte	0,004	1 %
●	Vaste voorzieningen	0,005	1 %	●	Terrein	0,000	0 %

Elementen

Funderingsbalken 0,007

Funderingsconstructies; voetenenbalken

Cat. 2 Fundatiebalken, Betonhuis; beton,in het werk gestort, C3037,CEMIII; incl.wapening+eps 370 m 0,007

Funderingspalen 0,001

Paalfunderingen; geheid

Cat. 2 Heipaal, beton, prefab, 250×250 mm, Betonhuis breedte 0.25 m breedte 0.25 m 68,92 m 0,001

Bodemvoorzieningen 0,000

Bodemvoorzieningen; grond

Cat. 3 Grondaanvullingen, Zand 220 m^3 0,000

dikte 20 cm x 1100m² = 220m³

Verdiepingsvloeren 0,031

Vloeren; constructief

Cat. 3 Vrijdragende Vloeren, HSB; Europees naaldhout balken, steenwol, multiplex, 2x gipsplaat; duurzame bosbouw dikte 338 mm 3.448,59 m^2 0,028

Plafondafwerkingen; verlaagd

Cat. 3 Afwerklagen, Spuitpleister dikte 3 mm 3.448,59 m^2 0,003

Vrijdragende vloeren 0,017

Vloeren; constructief

Cat. 3 Vrijdragende Vloeren, Houten kanaalplaatvloer dikte 338 mm 1.149,53 m^2 0,015

Vloerafwerkingen; nietverhoogd

Cat. 3 Bekledingen, Europees naaldhout; duurzame bosbouw dikte 12 mm hoogte 55 mm 4.230,27 m 0,001

Wat is dit? is dit het aantal meters aan bekleding op de vloer?

Cat. 1 Isolatielagen vloer, Knauf Insulation Naturoll 037 rwaarde 3.7 1.149,53 m^2 0,001

biobased isolatie geselecteerd. scoort beter

Vloeren, balkon en galerij 0,004

Vloeren; niet-constructief

Cat. 3 Vrijdragende Vloeren, Massief houtenvloer dikte 201 mm 300 m^2 0,004

Kolommen en liggers

0,004

Hoofddraagconstructies; kolommenenliggers

Cat. 3	Kolommen, Gelamineerd europees naaldhout; duurzame bosbouw	dikte 220 mm diepte 300 mm	894,6 m	0,004

Gevels, dicht

0,005

Buitenwanden; niet-constructief

Cat. 3	Systeemwanden, HSB element; Europees naaldhouten multiplex en gipsplaat; duurzame bosbouw	dikte 160 mm	560 m^2	0,002
Cat. 3	Isolatielagen, EPS	r-waarde 4.7 m2k/w	560 m^2	0,003

van 3,70 naar 4,70 conform Bbl

Binnenwandafwerkingen

Cat. 2	Houten planken van Europees zachthout vuren of grenen met mes en groef uit hergebruik handmatig geoogst door VERAS3		560 m^2	0,000

Gevels, open

0,066

Buitenwandopeningen; gevuld met ramen

Cat. 3	Buitenbeglazing, Drievoudig glas; droog beglaasd	dikte 12	891,52 m^2	0,063
Cat. 3	Waterslagen, Beton	breedte 165 mm hoogte 58 mm	405,32 m	0,001
Cat. 3	Waterkeringen, EPDM; folie	dikte 50 mm dikte 1 mm	891,52 m	0,001
Cat. 3	Buitenkozijnen, Europees naaldhout; geschilderd, acryl; duurzame bosbouw		445,26 m^2	0,001

Plat dak

0,009

Dakafwerkingen; bekledingen

Cat. 2	Plat dakbedekking, Stg. Dak en Milieu, Bitumen gemod. tweelaags 6,6 mm, 8,1 kg per m2, losliggend incl. ballast system 07, incl. 1x overlagen		1.077,15 m^2	0,006

deze staat er 2x in, 1 verwijderd.

Daken; constructief

Cat. 1	Isolatielagen dak constructief, Knauf Insulation Naturoll 035	rwaarde 6.3	1.077,15 m^2	0,002

Rc = 6,30 conform Bbl + biobased variant geselecteerd

Daken; niet-constructief

Cat. 3	Dak niet constructief, gootconstructie en dakranden, PVC		126,5 m^2	0,000

dakrand 126,5m

EPDM folie

0,000

Dakafwerkingen; afwerkingen

Cat. 3	Waterkeringen, EPDM aluminium versterkt	breedte 300 mm dikte 2.3 mm	126,5 m	0,000

dakrand ingeschat op 126,50m

Binnenwand openingen

0,011

Binnenwandopeningen; gevuldmetdeuren

Cat. 3	Binnendorpels, Kunststeen	hoogte 20 mm	160 m	0,002
Cat. 3	Binnenkozijnen, Staal; verzinkt+gemoffeld		396 m^2	0,004
Cat. 3	Binnendeuren, Honingraat; geschilderd:alkyd		160 st	0,005

Binnenwanden, niet-constructief-gemeenschappelijk

0,027

Binnenwanden; niet-constructief

Cat. 3	Systeemwanden niet dragend verplaatsbaar, Staalframe element; spaanplaat paneel; duurzame bosbouw		1.466,08 m^2	0,025
Cat. 3	Afwerklagen, Spuitpleister	dikte 3 mm	1.466,08 m^2	0,001

Binnenwanden, niet-constructief-woningen

0,004

Binnenwanden; niet-constructief

Cat. 3	Systeemwanden niet dragend bevestigingsprofielen, Europees naaldhout profiel	dikte 46 mm breedte 71 mm	2.191 m	0,000
Cat. 3	Afwerklagen, Keramische tegels; geglazuurd/gelijmd		501 m^2	0,003
Cat. 3	Afwerklagen, Spuitpleister	dikte 3 mm	1.690 m^2	0,002

Warmteopwekking

0,018

Warmte opwekking; hoofverdelingwarmte

Cat. 3	Warmtedistributiesystemen, Polyetheen/polybuteen; cv-leidingen; incl. koppelingen + verdeling	4.200 m^2gbo	0,011

Warmtedistributie; verwarmingslichamen

Cat. 3	Warmteafgiftesystemen, Vloerverwarming 95 Wm2; leidingen:kunststof	4.200 m^2gbo	0,007

Luchtbehandeling

0,032

Luchtbehandeling; luchtbehandelingskasten

Cat. 3	Luchtdistributiesystemen, Luchtbehandelingskast; mechanische ventilatie	4.200 m^2gbo	0,015

Luchtbehandeling; lokale(dak)ventilatoren

Cat. 3	Luchtdistributiesystemen, WTW-unit	4.200 m^2gbo	0,002

Luchtbehandeling; kanaalwerk

Cat. 3	Luchtdistributiesystemen, Ventilatiekanalen	4.200 m^2gbo	0,015

Verwarming

0,224

Warmtedistributie; verwarmingslichamen

Cat. 3	Warmteafgiftesystemen, Vloerverwarming; leidingen:polybuteen+toebehoren	4.200 m²gbo	0,015

Warmte opwekking; bijzonder

Cat. 3	Luchtwater warmtepomp, split unit, R134a, stuks 3 tm 4 kWt, NIET VERREKEND	vermogen 4 vermogen 4	40 stuk(s)	0,209

in plaats van ventilatieretourluchtwartempomp

Koeling

0,013

Koude-opwekking; centraal

Cat. 3	Koudeopwekkingsinstallaties, Compressiekoelmachine	4.200 m²gbo	0,013

Elektrische installaties

0,145

Beveiliging: Aarding en bliksembeveiliging

Cat. 3	Aarding, aarding woningen	4.200 m²gbo	0,005

Centrale elektrotechnische voorzieningen; energiedistributie, laagspanning,

Cat. 3	Elektricteitsleidingen, Geisoleerde installatiedraad + mantelbuis:pvc	4.200 m²gbo	0,004

Centrale elektrotechnische voorzieningen; energie, opwekking

Cat. 3a	Centrale elektrotechnische voorz.; energie, laagspanning, algemeen, Netstroom; NL-mix, 1 kWh (forfaitair)	92.000 kWh	0,061

Gemiddeld verbruik appartement = 2300kWh/J x 40 app = 92.200 kWh/j

Cat. 3	Elektriciteitsopwekkingsystemen, PV,mono-Si; plat dak; incl. inverter+steun+kabels	152 m²	0,075

1 paneel = 1,90m² * 80 stuks (2 per app) = 152m² (dit is een inschatting, aangezien we geen BENG berekening hebben)

Tapwater

0,000

Water; drinkwater

Cat. 3	Waterleidingen, Polyetheen; leiding+mantelbuis	4.200 m²gbo	0,000

Afvoeren

0,003

Afvoeren; regenwater

Cat. 3	Binnenrioleringen, Pvc; gerecycled; leiding	4.200 m²gbo	0,002
Cat. 3	Buitenrioleringen kavel, Pvc; gerecycled; leiding	4.200 m²gbo	0,001
Cat. 3	Hemelwaterafvoeren, Pvc; grecycled; diameter:80mm; d:1.8mm	250 m	0,000

Trappen

0,002

Trappenenhellingen; trappen

Cat. 3 Interne trappen, Europees loofhout; geschilderd, acryl; duurzame bosbouw 4 st 0,000

1 centrale trap

Balustradesenleuningen; balustrades

Cat. 3 Balustrades, Europees loofhout; spijlen; duurzame bosbouw 600 m 0,002

Balustradesenleuningen; leuningen

Cat. 3 Leuningen, Europees loofhout; duurzame bosbouw 100 m 0,000

Liften

0,002

Transport; liften

Cat. 3 Liftinstallaties, Staal; hefconstructie+contragewicht; 1 bouwlaag 4 st 0,001

4 bouwlagen

Cat. 3 Liftcabines, Staal; personenlift; gemoffeld 1 st 0,000

1 lift

Vaste voorzieningen

0,005

Vastesanitairevoorzieningen; standaard

Cat. 3 Toiletten, Wandcloset + fontein, porselein; incl. kunststof reservoir 40 st 0,001

Cat. 3 Wasvoorzieningen, Keramiek; wastafel 40 st 0,000

Cat. 3 Douchevoorzieningen, Inloopdouche, gipsblokken+tegels; incl. rvs afvoergoot 40 st 0,004