

Passive housing: the green future of real estate



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PASSIVE HOUSING: A VIABLE CONTRIBUTION TO ENERGY SAVING CONSTRUCTION

Passive housing is a quality assurance housing standard that aims to maximize the comfort and wellbeing of inhabitants and reduce the ecological footprint to a minimum. Such buildings make use of “passive” heating systems through efficient exploitation of the sunlight, internal heat sources and heat recovery methods.

The passive housing concept dates back to the 1973 oil embargo that severely hit the US economy: oil prices tripled in the United States, leading to a peak in March 1974, when a barrel of oil cost 12\$. This energy crisis encouraged a team of architects and engineers from the University of Illinois to come up with the Lo-Cal house in 1976: the energy consumption of this house was 60% less than the most efficiently up-to-date buildings at the time. This was the first step towards what is nowadays known as a passive house. The first time this term was actually used was in 1982, when physicist William Shurcliff became an advocate for energy-saving designs.

“What name should be given to this new system? Superinsulated passive? Super-save passive? Mini-need passive? Micro-load passive? I lean toward ‘micro-load passive.’ Whatever it is called, it has a big future” (William Shurcliff, The Saunders-Shrewsbury House, 1982).

Soon afterwards, the country that mainly focused on energy conservation and improved living comfort was Germany: physicist Wolfgang Feist improved the passive house design even further, developed a design that demanded 15 kWh/m² heating and founded the **Passivhaus Institute (PHI)**: this center is an independent research institute that aims to raise awareness for increased energy efficiency and to meet climate goals. Dr. Feist also built the first proper passive house residences in Darmstadt in 1991: this concept was so successful in Germany that further such buildings were constructed in the following years in Freiburg, Wiesbaden, Stuttgart and Hannover before the year 2000. The enthusiasm regarding passive homes quickly spread outside of Germany, and Sweden, France, Switzerland and Austria became advocates for environmentally friendly solutions and energy saving building designs: as a matter of fact, at the beginning of the new millennium 221 further passive accommodations had been built in these five countries according to the CEPHEUS, namely the Cost Efficient Passive Houses as European Standards (Lozanova, 2019).

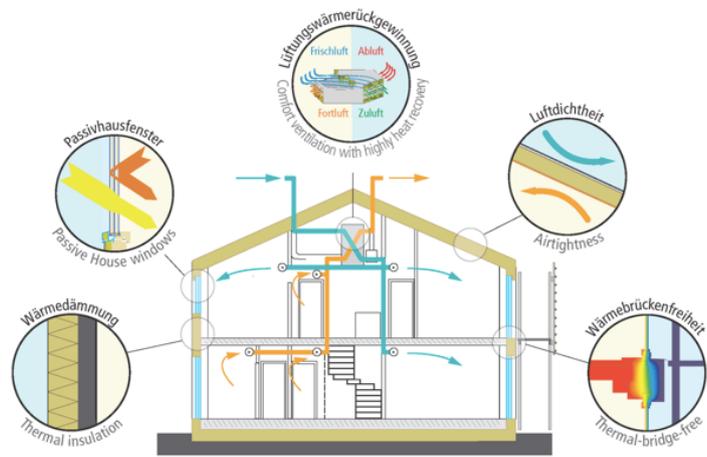
Nowadays there are approximately 60 000 passive buildings in use worldwide, and Germany alone accounts for about a third of these.

According to the Passive House Institute, several criteria must be met by a building for it to be classified as passive.

- **Primary energy**

The passive house standard decreases the total primary energy requirements of a building by more than 70% compared to an average new building. In fact, these new buildings were mostly built according to the EnEV (abbreviation for the German term *Energieeinsparverordnung*, a regulation dating back to 2001 which concerned the energy use of newly built or recently renovated buildings at the time).

In turn, these EnEV buildings obtained almost twice the savings of old building. The remainder is a primary energy demand reduced by a factor of 6 (17%) in contrast with an average old building. The crucial part in this reasoning is that since the demand is so low, renewable sources of energy that are usually readily available can cover it in a sustainable and environmentally friendly way.



The principles of a passive house according to the PHI, 2015

- **Airtightness**

Airtightness refers to the problems that may arise when there is a gap with airflow from inside out. In fact, if a building is not sufficiently airtight, humid outside air can penetrate into the construction and lead to unpleasant consequences, such as the formation of mold and damaged walls. A good level of airtightness, which prevents moisture penetration in building components and condensation on colder parts of the construction, leads to better sound protection, reduced drafts of air and an overall increased level of comfort for inhabitants.

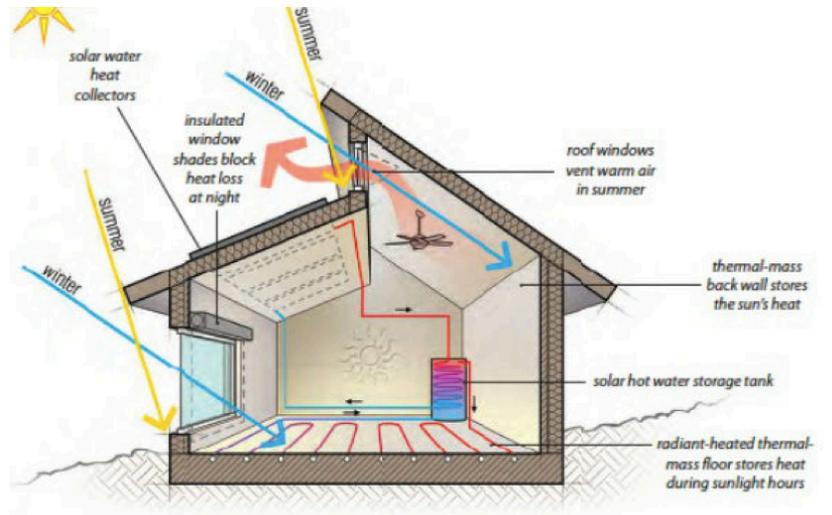
The importance of airtightness is not only relevant now that passive houses have emerged: even when designing regular homes, architects try making the external layers of buildings as airtight as possible, since that is the best solution to avoid penetration of moist air into the construction and the subsequent damage.

There are two airtightness criteria that must be met to classify a building as passive: it must meet either 0.60 air changes per hour at 50 pascals based on its volume or 0.05 cubic feet per minute at 50 pascals, per square foot of building. The preferred way of making sure these criteria are met is to use a blower door during construction to test the air barrier enclosure.

- **Space heating**

A fundamental requirement is that the passive house may use up to 15kWh/m² for heating and cooling, calculated on a yearly basis. Alternatively, the energy demand for space heating may reach 10W/m² at peak demand. This constitutes an immense saving when compared to the amount of energy needed in a regular home, which reaches up to 100W/m². The way in which architects and engineers design such heating systems is by assessing where the sun

exposure is and then trying to retain as much heat as possible in the cold winter months while keeping it out when temperatures rise: in fact, in the winter there are fewer hours of daylight and the sun hits the surface of the Earth at a lower angle than in the summer, so this technique makes the most out of the natural seasonal position of the sun.



Signature Sustainability, *Details of passive solar heating*

This passive solar design is fundamentally different from an active solar design: in fact, as we have stated, the former simply determines how the sun moves so that the house can be built accordingly, while the latter makes use of expensive arrays of photovoltaic or thermal solar panels (Johnson, 2017).

- **Thermal comfort**

As far as thermal comfort is concerned, in a passive house no more than 10% of the hours in a given year should exceed 25°C: this is achieved by making use of triple glazed windows and insulated frames, which retain a pleasant warmth and prevent excessive heat from entering. As opposed to regular heating or cooling technologies, this system enables the walls and the floors to stay at the same interior temperature, regardless of the outside temperature. The reason why this criterion is pivotal in passive housing is that research carried out by Danish Professor P.O. Fanger shows that thermal comfort is the main factor that influences overall living comfort. Optimal thermal comfort is achieved when the human body releases the same amount of heat that it produces: thanks to the aforementioned highly insulated construction, the difference between the indoor and outdoor temperature of passive houses is close to none all year round. (Grove-Smith, 2018).

COSTS AND AFFORDABILITY

Apart from the previously mentioned environmental benefits that come with passive houses, there are many economic advantages that need to be mentioned.

At first glance, building a passive house can seem prohibitively expensive. In fact, there are three main factors that contribute to the building costs, and there are several ways to try and reduce them.

- The first factor is the **complexity of the design**: the more complicated the wished design, the costlier to build. However, recent trends towards minimalism and a no-frills lifestyle suggest that homeowners and homebuyers are looking to build simple homes with a sleek and ordered layout. As a matter of fact, when complexity exceeds capacity the result is unhappy customers, frustrated suppliers and a great waste of resources. Therefore, adopting a leaner, cleaner building approach can greatly reduce construction costs.
- The level of **finishing** can too influence the cost of a passive house to a great extent: in fact, the cost per square foot of a passive home can range anywhere from 150\$ to 500\$, depending on the chosen finishes. The reason why this factor is worth mentioning is that regardless of the chosen type of finishing, the energy performance of a passive house doesn't change, so it's just a matter of aesthetics.
- A self-explanatory factor that contributes to the costs associated to building any house is its **size**: the greater the size, the greater the cost.

On top of the solutions mentioned in the previous list, there are additional strategies employed by builders and architects to make passive houses more economically attractive for customers who are skeptical about the high initial investment. For instance, to make the most out of these houses' ability to run on solar gains, the building site is optimized so that as much sunlight as possible is retained in the winter months: in fact, if carefully designed, 50% of the heating energy can come from the sun alone. This **strategic positioning** will allow a significant reduction in the thickness of the necessary insulation and, consequently, in construction costs.

Another consideration worth mentioning is the design of a building shape that will minimize the **ratio of the exterior surface area to the floor area**: this is because passive buildings cost approximately 5-10% more than a regular house. For example, building a passive house in Germany costs 8% more than usual, but this differential increases in countries where such designs are a novelty.

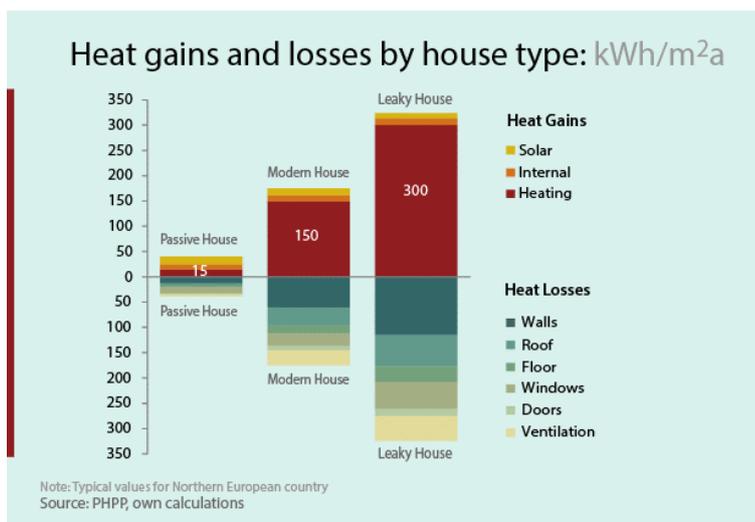
However, it should be noted that the aforementioned factors only regard **initial investment**; these houses save money **in the long run**, so the main financial benefits of passive houses become apparent years after building them.

Furthermore, in recent years governments have introduced **incentives** to build passive houses and to renovate existing houses to make them as energy saving as possible: this makes passive houses more accessible than ever. To be eligible for such incentives, future homeowners must obtain a

passive house certification of their building and hire a certified consultant who will scrutinize the energy consumption and make sure that it meets the needed criteria. This feasibility study will be thoroughly monitored by the country's Passive House Institute.

These incentives don't concern private houses alone: for instance, the City of Seattle submitted an incentive proposal regarding condominiums, whereby additional floor area and an extra story could be built. This would mean that, if these incentives were to be made use of, rather than a six-story building there would be seven, rather than seven stories there would be eight, and so on. This incentive program would be a novelty, since most multi-family homes are not governed by the number of units that can be built: according to this program, by allowing passive house projects more floor area and additional stories, more individual passive homes will be built. This proposal has yet to be accepted, but it would certainly improve the amount of passive homes in the US, and if this project resulted in a great success, such proposals could be supported in further countries as well (DiRaimo, 2020).

In addition to this, the investment in peculiar high-quality building components are offset by the **elimination of any cooling or heating systems**: there are no costs associated with installing a central heating system or paying hefty bills, and the rising energy costs don't affect inhabitants of passive homes.



As previously stated, and as can be seen in the following graph, a passive house needs 15kWh/m² of heating energy per year, which adds up to approximately 60€ per year. On the other hand, a historical villa of similar size uses around 300kWh/m², which adds up to an impressive yearly bill of 1150€ (Marcus, 2020).

Moreover, the fact that there is less technology that can go wrong means that the high **maintenance and repair costs** associated to ordinary homes can be significantly reduced. In particular, passive houses are known to have extremely valuable plumbing systems that provide long-term desirable results and that lessen the maintenance costs of maintenance. In fact, in recent years brass plumbing fittings have become the most popular choice of plumbing components, and have shown great durability and efficiency. This is because brass offers several benefits compared to other materials, such as iron or steel: for example, they have excellent resistance to corrosion, so if passive houses are built in areas where water is highly corrosive, it is advised to use brass fittings. As a matter of fact, rust and corrosion are the two main causes of plumbing issues that lead to pricey repair costs. Another reason why brass components have proven to be most adequate in the long run is that they are highly malleable: this will make plumbing works easier and cheaper thanks to the ease of work, and maintenance will be easier because of the versatility of brass compression fittings. In addition to this, in passive houses there is no manifold pipe distribution, since plumbing

designs tend to be centralized, which reduces costs further: in fact, since plumbing is most important in bathrooms and kitchens, plumbing systems are built in such a way that all hot water lines are insulated and that there are fewer heat losses while the water tries to reduce its destination.

A factor that can greatly decrease the costs of building passive houses is the **local availability of building components**: in fact, importing raw materials or mechanical systems from abroad is more expensive than using locally accessible resources, costlier to install and harder to service in the future.

Furthermore, the efficiency of passive houses depends on the **local climate**: as a matter of fact, depending on local humidity, rainfall and hours of daylight special attention must be paid to building materials and the house design, so that the resulting home meets all the passive house requirements and offers the utmost comfort to its inhabitants.

In 2015, Researches Jürgen Schnieders, Wolfgang Feist and Ludwig Rongen conducted a study to demonstrate the approaches to the building of passive houses in all of the world's relevant climate zones; they chose Yekaterinburg (Sweden), Tokyo (Japan), Shanghai (China), Las Vegas (Nevada), Abu Dhabi (United Arab Emirates) and Singapore as sample countries to carry out their research. The obtained results were incredibly interesting as far as the different measures that must be taken are concerned: for instance, in the biting cold of Yekaterinburg the main concern was making sure that an efficient heat recovery system that provided frost protection was used. This was achieved by installing a 50cm thick insulation and a rotary wheel energy recovery ventilator that wouldn't freeze above -20°C. The low temperatures lead to low humidity ratios, so installing dehumidification systems wasn't necessary. In Tokyo the winter temperatures weren't as low as in Sweden, so less insulation was needed since solar radiation levels are greater. However, the high air humidity in the summer months makes dehumidification measures essential, so an automatically operated bypass of the ventilation heat recovery was installed. In Abu Dhabi temperatures are above 10°C year-round, with a summer peak of 40°C. Building a passive building under such conditions is fairly easy, since there's no demand for heating energy, and the main focus shifts to cooling demand: the preferred ways of allowing heat protection are triple solar protective glazing, eaves that reach out one meter around the house to reduce direct sunlight on the façade and insulated basements. Since temperatures are quite high even in the winter months, it's often sufficient to open the windows to provide passive cooling inside the house (Schnieders, Feist, Rongen, 2015).



An example of passive house in Karuizawa (Japan), designed by Kevin Meyerson

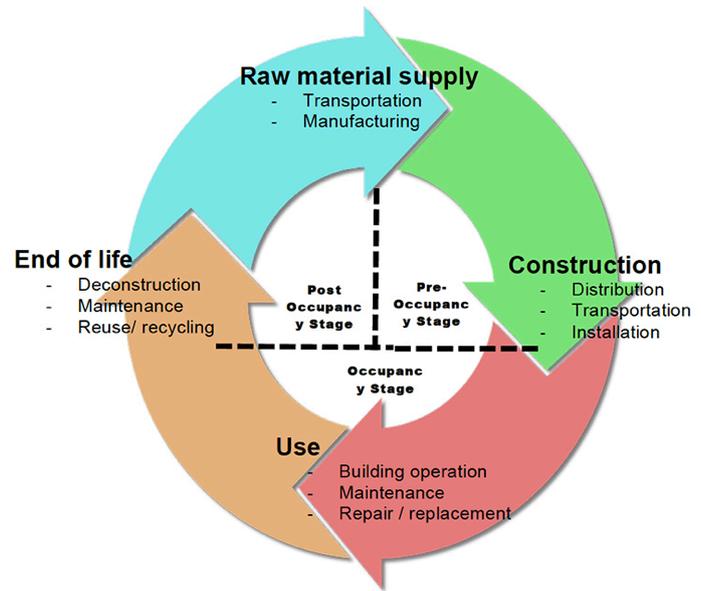
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These examples are to show that passive houses can be built in very different, if not extreme, climates and it's therefore possible to have them nearly anywhere in the world. The thing that

architects and engineers keep in mind is that different climates require different measures to be taken and, consequently, different design tools and building materials: oftentimes these are most easily found on local sites, since even non-passive houses require them, so looking to import certain technologies and resources from abroad is inconvenient and leads to unnecessary costs (Sedam, 2019).

LIFE CYCLE ASSESSMENT

An interesting approach that has been widely used in recent year when it comes to the evaluation of the impact of houses on the environment is the **Life Cycle Assessment**: this provides a framework to help assess the environmental consequences of products and services employing a “cradle to grave” perspective: this means that every single step in an object’s lifecycle is considered, from extraction of raw materials to the demolition and disposal of the final product. Among the criteria that are analyzed to assess the sustainability of



Wildenlivinglab, *Life Cycle Stages of a Building*

products and services, there is the amount of water consumed, transportation costs and carbon footprint. This approach is particularly popular in the building sector because buildings make up 40% of the total energy demand and because they contribute to 36% of the total emissions in Europe: therefore, understanding where these impacts originate and how to keep them under control plays a crucial role in the fight for a greener, safer and healthier planet (Psarra, 2019).

A building’s life cycle is usually comprised of four stages:

- The **product stage** is concerned with the impact of the raw materials necessary for building purposes until they reach the factory: this refers to the extraction of raw materials, their transport to the factory and the outcome of the manufacturing of the final product. The extraction of non-regenerative raw materials is an energy intense activity that requires large scale interventions in ecosystems: this leads to water imbalance and thus air, soil and water pollution. This issue refers to renewable source of energy as well, albeit to a lesser extent: in fact, the main negative consequences of the use of renewable energies mainly concerns manufacturing and transporting. For instance, the production of photovoltaic cells generates toxic substances that may contaminate water resources. As has already been explained, passive houses don’t make use of such active systems, so their environmental impact during this stage is fairly low.
- The **construction process stage** refers to the effects that the construction process has on the environment until the building is practically complete. According to a Spanish research paper

published in 2010 (Oscar O Ortiz-Rodriguez, Jorgelina Pasqualino, Gloria Díez and Francesc Castells, *The environmental impact of the construction phase: An application to composite walls from a life cycle perspective*), the amount of carbon dioxide emissions that result from the construction stage consist of the following: packaging waste represents 16% (roofing 31%, structural frame 22%, architectural finishing 15% and internal and external walls 10% of the total waste), while the use of materials accounts for 84% (internal and external walls 30%, architectural finishing 23% and foundations and basement 19%). There are multiple ways in which the environment suffers the consequences of the construction stage: for instance, noise pollution (machine engines, installation and materials processing noise), consumption of mechanics (machine maintenance and depreciation charges), power consumption of assembly systems (tower cranes for industrial use) and hoisting malfunction (if hoisting machines are used improperly, with an incorrect lifting point, with heavy wind or hoisting undulation, there can be significant loss of components, which can have serious outcomes). In addition to the aforementioned issues that arise from construction, building a house also leads to major quantities of wastewater, fuel consumption and vehicle exhaust, such as gases or steams (Kumar, 2018).

The ways in which building houses sustainably can be achieved is by minimizing, if not eliminating waste: for instance, durable modular metal form systems for use in concrete construction can be selected based on whether they can be easily demounted and reused elsewhere. Interestingly, concrete is one of the most frequently used materials when building passive houses: this is because concrete and concrete masonry walls don't require the installation of any membranes because of their inherent airtightness. In addition to this, concrete is able to absorb a great amount of moisture from the ambient air and release it back into the house once the moisture-causing process (cooking or bathing) has taken place: this helps to balance the internal humidity levels. Another formidable property of concrete is that it can easily capture, store and let out the sun's heat to balance out internal temperature fluctuations (Napier, 2016).

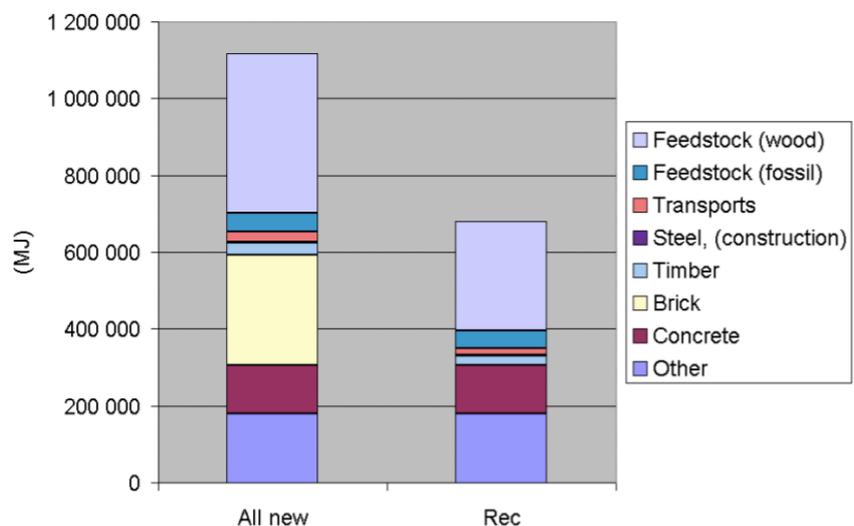
- The third stage is the **use stage**, which considers the impacts from operations such as maintenance and repair, refurbishment and the building's energy consumption during its lifetime. This is the stage that most negatively affects the environment: in addition to being extremely costly for the homeowner, the consumption of heating and cooling energy is the major cause of environmental pollution. For example, burning fossil fuels is the main contributor to the emission of greenhouse gases, as it releases nitrogen oxides into the atmosphere, thus contributing to the formation of acid rain and smog. Furthermore, energy usage leads to water pollution issues: the generation of energy heavily relies on water availability, and the pollutants released from energy industries lead to severe water pollution, which further worsens water scarcity. This polluted water affects the aquatic ecosystem and human health because of toxic chemical components. These are just two of the many negative implications that the energy consumption has on the environments and on our lives, and passive houses can reduce them to a large extent: as has already been mentioned, they use a combination of low-energy building techniques and technologies, such as superinsulation and passive solar designs (Liu Yu, 2018).

- The last stage is the **end of life stage** includes demolition, waste transport to the ultimate destination and their final disposal. This paper has already stressed the relevance of using high-quality, durable materials, and the reasons in favor of that become apparent in the last stage of the Life Cycle Assessment. Let's consider material A, with a high environmental impact but without any replacement needs, and material B, with a low environmental impact but with a greater substitution need. All else equal, material A should be the obvious choice: this is because even if the material itself negatively affects the environment more than B, it doesn't ever need to be replaced in a lifetime, thus only going through one lifecycle. In fact, if we B were the chosen building material, it may pollute less in the short run, but it would need to be disposed of frequently and new materials would be needed, so more individual items would go through their lifecycle, leading to excessive pollution.

An additional stage that isn't strictly speaking part of the lifecycle of a product is linked to **the benefits and the loads beyond the system boundary**, which refer to the potential consequences that derive from the reuse and recovery of the materials after demolition.

A study conducted by Catarina Thormark, from Malmö University, shows the differences between the costs and the environmental impact of houses built with recycled materials and houses built mainly using new components. The result of this research showed that the recycled house significantly reduced the use of raw materials and reduced transportation costs.

Recycled raw materials such as bedrock, sand, clay and timber allowed a decrease in their use of approximately 30%, while fossil resources for energy production decreased by 25%. The use of different chemicals decreased by about 80%. The detailed results of this research can be analyzed in the following bar graph.



Thormark, *Environmental analysis of a building with reused building materials*

In addition to the reused materials, this study also examined the different magnitude of environmental impact of a recycled house versus a new house; stated as percentages of the entirely new house, the results for the recycled house were as follows: 70% global warming potential, 50% acidification, 70% eutrophication (enrichment of water by nutrient salts that causes structural changes to the ecosystem) and 61% photochemical ozone formation (Thormark, 2020).

CONCLUSIONS

The passive house principles are among the most recognized in sustainable construction, and its properties, such as high thermal insulation, extreme airtightness and comfortable temperatures are leading to an increasing popularity and worldwide success.

When pondering on the possibility of building a passive house, the high initial investment may seem off-putting at first. However, one should always consider the benefits that result from such a decision in the long run: the maintenance of a controlled atmosphere saves a great amount of money in terms of repair costs and hefty monthly bills, and the near-constant temperatures make it an incredibly comfortable home.

Among the main advantages to building a passive house is the contribution to a healthy living environment and to climate protection: passive houses are now considered the world's most energy-efficient standard, since they reduce their dependence on fossil fuels and carbon emissions to a minimum. Since more than 60% of a common building's energy use goes toward heating and cooling, the high-efficiency heating and ventilation systems keep overall consumption as low as possible, so that as much energy is consumed as it's produced.

The fact that these net-zero homes make use of the natural position and energy of the sun doesn't mean that they can only be built in places that are sunny year-round and where temperatures are mild: through a thorough analysis of the local climate and an evaluation of the needed construction materials, passive houses can be built anywhere in the world, even in places with brutal winters and frequent rainfall.

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