Energy and cost analysis of double and triple glazing

Introduction

In western society buildings can be responsible for more than 30% of the national energy usage and greenhouse gas emissions. In the search for solutions to combat these issues and reach the targets of policy agreements, new building materials and construction methods are introduced frequently, as is the case with triple glazing. In recent years there are movements to make the use of triple glazing mandatory through building codes or performance standards in the Netherlands, instead of double glazing. There are many studies done on triple glazing, but none to compare the actual energy costs and benefits for various comparative products for the Dutch climate. Therefore Except has initiated a small research project using energy analysis software, basic cost calculations, LCA data and recommendations from the industry to review the consequences and characteristics of triple glazing versus double glazing.

What is triple glazing?

Triple glazing can take the form of a variety of products. Commonly, it is similar to a standard double glazing unit with an extra pane of thin glass inserted in the cavity between the other two glass planes (fig. 1) using a spacer[1]. The two chambers that are thereby created inhibit convection and allow for a higher insulation value than with double glazing alone. The chambers can contain air, or filled with a gas that increases the insulating properties of the unit (for these units the 'HR' abbreviation is used). In Scandinavia the use of triple glazing has seen some following due to the cold winters. In the Netherlands, due to the more temperate climate, this product has only recently appeared on the market. A triple glazed unit is not necessarily thicker than a double glazed one, but it is considerably heavier. This incurs costs for fabrication, storage, transportation, handling and placement.

The *insulation value* UGlass is the degree of resistance to convection and conduction energy loss, the lower the better, expressed in $m^{-2}\ K^{-1}$. Double HR glazing has a value of around 2, HR+ between 1.6 and 1.1, and HR++ a value lower than 1.1. Triple glazing can be indicated by 'HR+++'. The *transmission value* of glass determines how much radiation can penetrate the glass, consisting of both a heat and light component, and varies among products.

Experiments with filling the cavity with insulative aero gel have been performed, reaching U values lower than 0.7[2], but are not yet widely available. Also, research into creating a vacuum in the cavities resulting in U values as low as 0.2[3] is underway, but also not yet available.

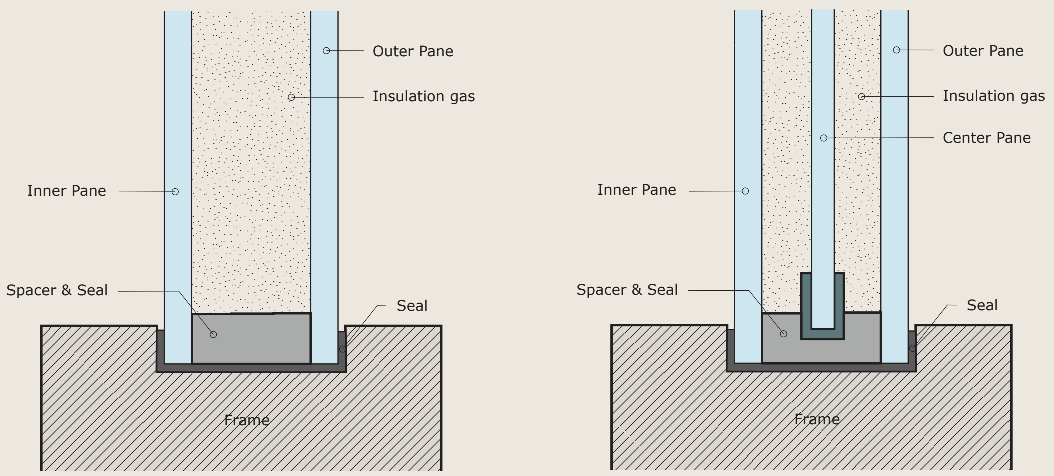

fig. 1

Experiment

This experiment focuses on the following three questions:

- The energetic performance of glass types (does triple glazing reduce required heating energy?)
- The environmental impact (are the extra energy and material for fabrication less than its savings?)
- Cost (is it financially beneficial to invest in triple glazing?)

The energetic performance is measured using computer analysis software, which also gives us our usage cost. Using life cycle analysis data a comparison is made concerning the environmental costs of the product itself, and a quick cost comparison shows the financial benefits and drawbacks between products.

Experiment setup
The experiment is setup for residential usage, and uses as a model a worst case scenario of a small single freestanding house with one occupied layer. The house is 10x10 meters square with openings on each side. There are four variants of the house used, to measure the effect of south glazing and a comparative measure such as better wall insulation. The house has an average Dutch activity schedule and climate, has floor heating and a gas powered high efficiency heating installation.

Variant 1: 10% North glazing, 20% East/West glazing, **30%** South glazing, **100mm EPS** wall insulation
Variant 2: 10% North glazing, 20% East/West glazing, **90%** South glazing, **100mm EPS** wall insulation

Variant 3: 10% North glazing, 20% East/West glazing, **30%** South glazing, **140mm glasswool** insulation
Variant 4: 10% North glazing, 20% East/West glazing, **90%** South glazing, **140mm glasswool** insulation

Variant 1 and 2 have average building materials for the Netherlands (brick, eps foam, concrete, gypsum), and variant 3 and 4 have increased wall insulation and 20% less infiltration through gap treatment.

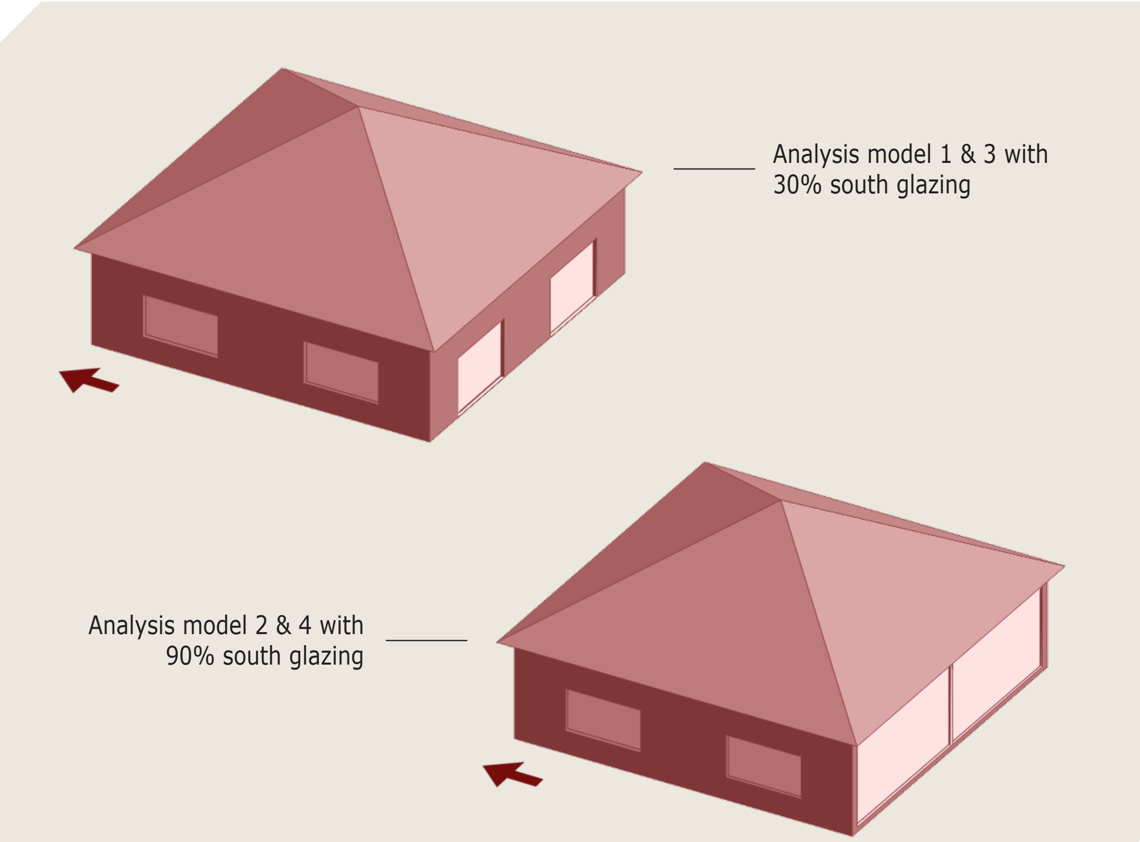

fig. 2

These houses were then outfitted with various double and triple glass types, and one single plate glass type as a reference, and were then modeled and analyzed using EnergyPlus, a comprehensive environmental calculation and analysis algorithm for buildings. This method generates a variety of data, among which total energy use for gas and electricity, solar gains, and CO2 generation. The advantage of using such an analytical model is that various other parameters are taken into account, such as airtightness, real-world climate data on a day-to-day basis, usage characteristics, etc. Reliable and repeatable experiments can be performed in for regression testing. EnergyPlus does not take into account all possible physical processes that are taking place, such as temperature gradients over the glass surface, or angle dependence for solar energy transmittance[4], which we predict for this experiment not influence the results in a significant way.

Tested Glass Types

There are many glazing types available on the market. For this experiment five types of glazing were tested, all commonly used products in the building industry, and standardized for EnergyPlus calculations. A single plate glass type is used as a reference, and for each double and triple glazing unit a high performance variant is added. "UGlass" is the insulation value, and "Trans." the transmission value.

Type:	**Single**	**Double**	**Double HR**	**Triple**	**Triple HR**
Glass:	6mm helder	6mm/13mm	3mm/13mm	6mm/13mm	6mm/13mm
Filling:	-	Air	Argon	Air	Argon
Characteristics:	Uglass = 5.36 Trans. = 0.351	Uglass = 2.45 Trans. = 0.216	Uglass = 1.60 Trans. = 0.688	Uglass = 1.21 Trans. = 0.303	Uglass = 0.78 Trans. = 0.470

Energy Calculations

The graph in figure 3 below shows the total energy usages of the various glazing types and for the 30% and 90% south glazing houses, as well as the models with increased wall insulation. It's immediately clear that there are large benefits to using double glazing types and beyond. It's also clear that the double HR glass outperforms the normal triple glazed unit.

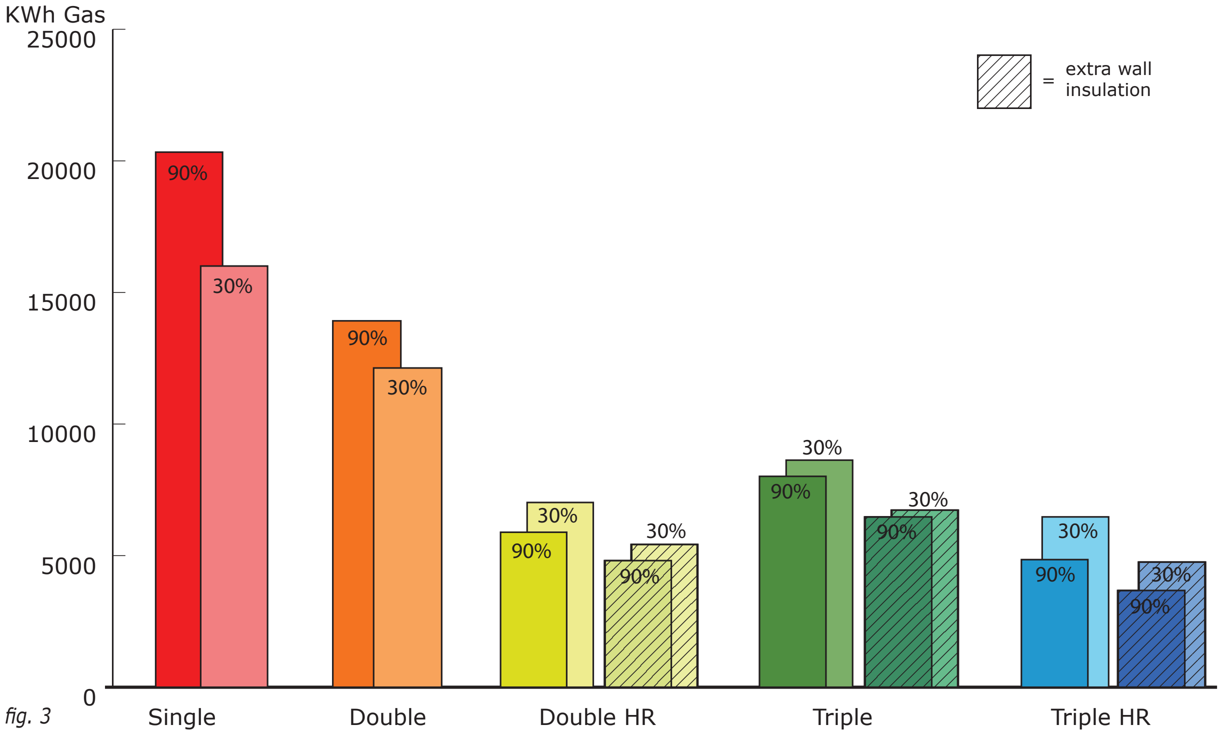

fig. 3

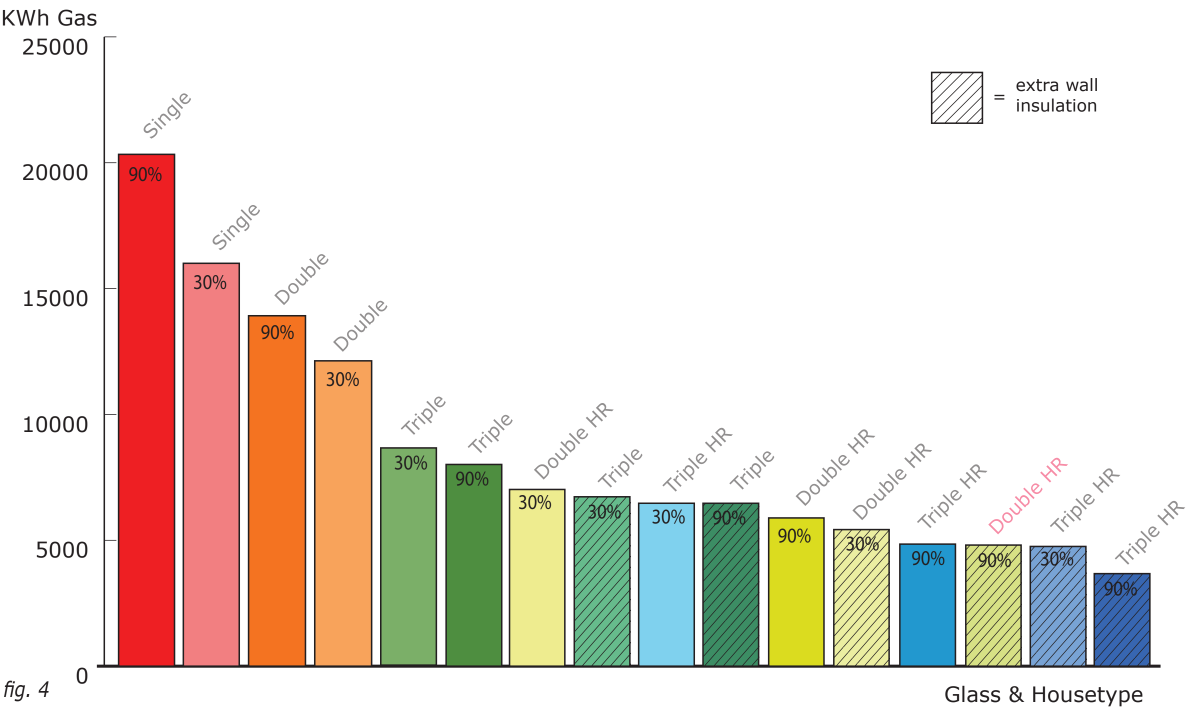

fig. 4

As we can see in figure 4 as well, triple glazing alone is not a guarantee for lower energy usage, nor automatically a better investment over better wall insulation. It is dependent on the specific type of triple glazing used, the unique conditions of the location, house design and placement, insulation of the other construction components and the transmission characteristics of the glass.

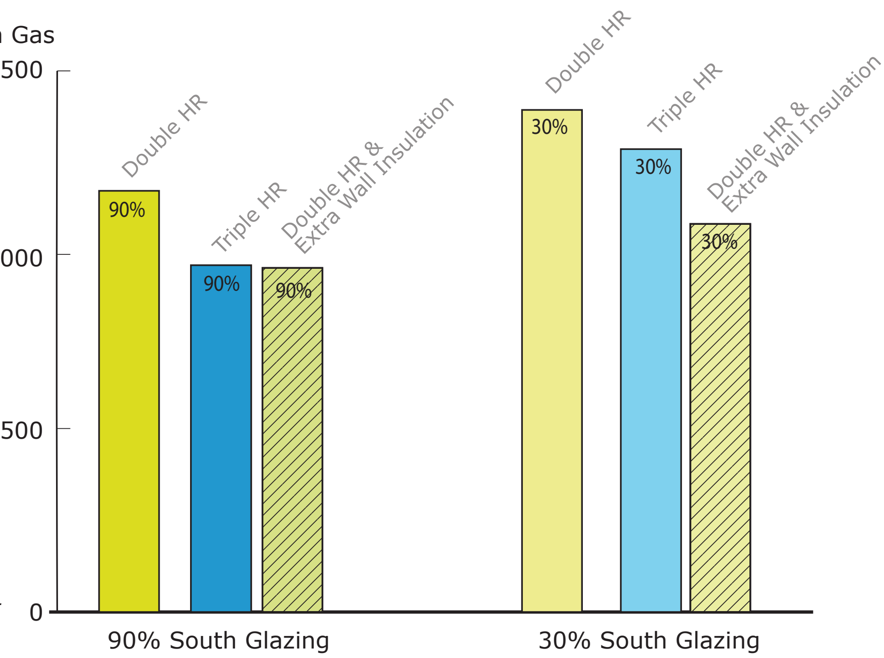

fig. 5

Figure 5 shows us that extra wall insulation can be an equal or better improvement to the energy usage of the house than even high performance triple glazing.

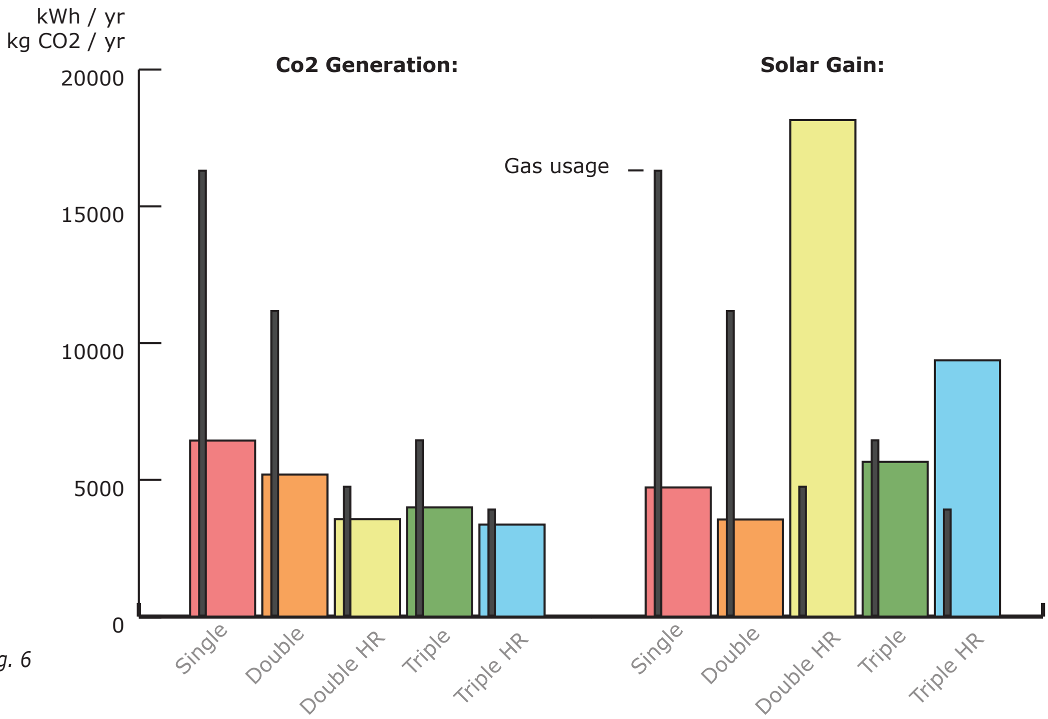

fig. 6

The left side of figure 6 shows the gas usage versus CO2 emissions. We can see that they are related, but that CO2 emissions are not decreasing by as much as the gas usage of the entire house. This is due to other forms of energy use within the house such as electricity and water. This means that only a limited amount of CO2 reductions can be affected by triple glazing.

On the right of figure 6 we can see a large difference in solar gains between the different glazing types due to the difference in transmission values. Glass with a higher transmission value admits more light and heat from the sun. In winter this has a direct effect on gas usage, and the effect is in the same order of magnitude as the gas usage itself. This explains why the double HR glass outperforms the normal triple glazing, despite the higher insulation value of the triple glass, because the double HR glass allows more solar energy to enter the house.

The CO2 reductions resulting from using Triple HR glass instead of Double HR are approximately 200 kg a year. This is a reduction of 5.5%, equivalent to approximately 1/40th of the output of an average car a year.

Cost Calculation

Following a simplified version of an existing model[5], we compare the total cost of ownership with the extra implementation costs with the benefits gained during the life span of the product. Only the double HR and triple HR products are shown, for a period of 30 years, for the house with 90% south glazing (37m^2 glass surface). We are using a value of 45 euro/m^2 for double HR and 125 euro/m^2 for triple HR glazing[6].

Implementation costs double HR:	1665 euro
Implementation costs Triple HR:	4625 euro
Cost Difference:	**2960 euro**

Energy costs are calculated using a value of 3% and 6% rise in gas prices per year. The base difference in costs at year 0 is 103 euro[7], which follows from the difference in gas usage per year, multiplied by the gas price. Figure 7 shows the cumulative financial gain over a period of 30 years.

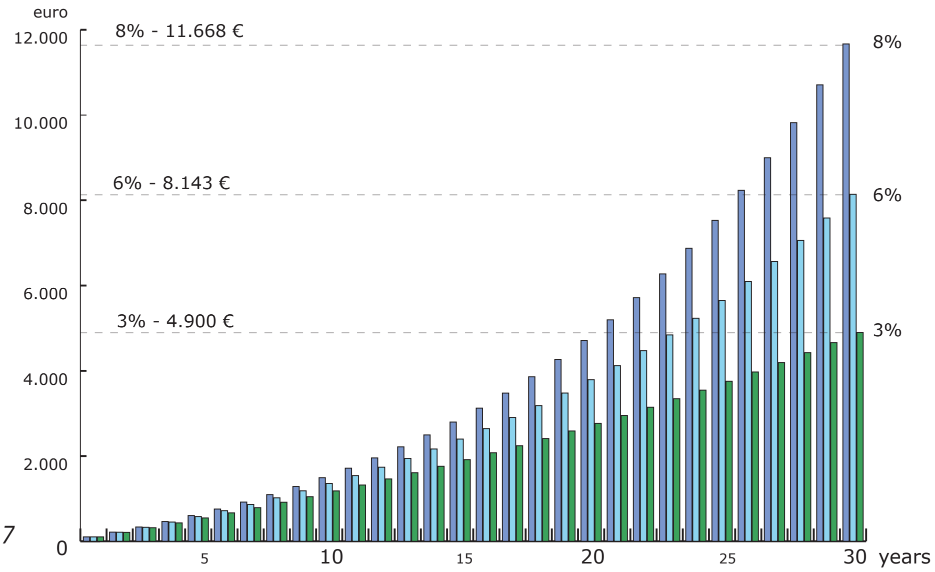

fig. 7

The total savings in gas usage over 30 years is 3500 m3. With an interest rate of 4% we can calculate the cost savings back to its current cash value:

Current value of total savings in energy cost with 3% price raise per year after 30 years: **1510,84 €**
Current value of total savings in energy cost with 6% price raise per year after 30 years: **2510,64 €**
Current value of total savings in energy cost with 8% price raise per year after 30 years: **3597,51 €**

Return on Investment (ROI) is the time period in which the investment has paid for itself. The ROI for 3% and 6% rise in gas prices is more than the lifetime of the product, and the ROI for 8% rise in gas prices is more than 26 years. This is a very low ROI often insufficient for investment by consumers or private parties.

These calculations may be affected in the future by price reductions due to increased production in the Netherlands.

Life Cycle Analysis

Using Life Cycle Analysis (LCA) data we can investigate what the difference in energy costs is during the entire cycle of a product's life, including raw resources, fabrication, transportation, maintenance and disposal. The actual costs are of course dependent on the location of application, re-seller and individual manufacturer, but using comparable data we can make an estimate of the expected performance.

LCA Calculation[8]:

Double HR: 547 MJ non-renewable energy
29 kg CO2eq = **151.9 kWh/m²**

Triple HR: 837 MJ non-renewable energy
40 kg CO2eq = **232.5 kWh/m²**

The difference in energetic life cycle costs for the triple glazed unit is 80.6 kWh per square meter of product, and almost 3000 kWh for the entire house. With an energy saving of more than 1000 kWh per year compared to the double glazed unit, the extra investment in total life cycle costs is entirely warranted, and regained within three years. Triple glazing would repay its extra 11 Kg CO2 cost in its material lifecycle in just months.

Note that this LCA data assumes the products come from the same factory, and are delivered at the same location. In reality, this will not be the case. Triple glazing is only available from select firms, sometimes even only in another country. The extra transportation cost, which will be significant, needs to be factored in for each case separately. If the triple glazing comes from Sweden, and the double from a local source, this extra transportation cost will likely double or triple the environmental cost.

Conclusions

Please mind that all these results are based on a particular climate and experiment. Triple glass performs better than double glass, and wins back its life cycle and financial costs over the lifetime of the product if:

- ... The primary energy generation for the house is on gas or a similar fuel according to the standard used in this experiment. With a zero-energy house, for instance, the characteristics will be much less beneficial.
- ... Direct solar-gain is used as a form of energy gain, and the transmission value of the triple glass does not remove too much solar-gain compared to the alternative glass unit.
- ... The triple glazed unit is of high enough quality. There are triple glazed units that perform worse than (much cheaper) double glazed units.

All these factors are heavily influenced by orientation, ventilation, internal load changes, and other construction materials[9].

Drawbacks:

- Triple glazing is considerably heavier than double glazing. This increases transport and placement costs. It can also become the cause of increased injury in the work place. Lifting glass is already a health hazard with double glazed units.

- The return on investment (ROI) is very low due to the high price of triple glazing, and the modest energy savings.

- Energy gains for triple glazing will diminish if the insulation of other parts of the building are increased, or if less glazed surface is used. Only the high performance triple glazing units have energy and cost benefits, and in the Netherlands it's already common practice to use very high performance double glazing with a Uglass of 1.1, better than the double glazed HR glass used in this experiment.

- Applying triple glazing requires a careful investigation of its particular performance. Transmission values are of high importance, glazing types that inhibit solar gain have higher energy usage characteristics.

- In many cases more energy and emission reductions can be achieved by other means, such as better wall insulation and closing of infiltration gaps, than by applying triple glazing. This means that making triple glazing mandatory will force the usage of a solution that may not be as effective as other solutions, or not beneficial at all, while still incurring costs, hazards and extra life cycle energy investments.

Advantages:

- Triple glazing has better sound insulation properties than double glazing, and can thus be used as an extra advantage in areas with sound problems.[10]

- Good triple glazing has less problems with condensation issues than double glazing.

Long-term consequences

The question whether a government should prescribe a specific solution, or should focus on the outlining of required performance goals is relevant here. Requiring the application of a certain specific product type can increase the performance of the bottom end of the spectrum. However, it can also be in the way of improvements attempted in the other end. In some cases changes in design are a better way to save energy than the application of any specific product, such as triple glazing. The quality of the offered products also influences the performance of these prescribed measures, resulting in for instance some double glazed units outperforming triple glazed units, making the resulting policy measure miss its target. The higher costs and risks of triple glazing will become a major drawback in issues like these. Also, new development like aero-gels and vacuum cavities allow an even higher insulative properties than current products. Basing a policy prescription on a technology that is still in midst of development is inadvisable.

With passive-house and zero energy building design becoming more and more common in the industry, the balance of these measures shift as well. When total energy usage is zero, and which can be achieved with double Hr glazing alone, it would not be beneficial to apply triple glazing in most circumstances. This would also unnecessarily drive up the cost of construction, costs that could be better applied elsewhere.

Except has the opinion that stimulation of performance increases should only occur on the basis of performance outlines, and that the mandatory usage of certain products or product groups will often not benefit the overall targets of the policy measures.

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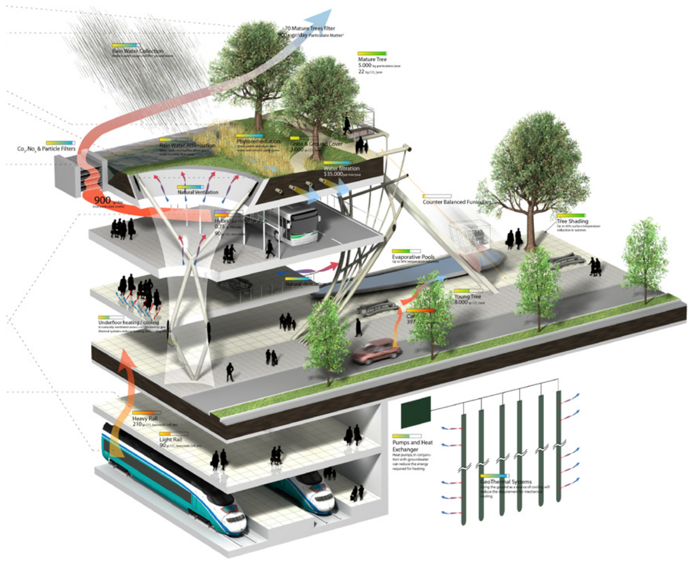

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