REPORT
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D.6.8 Adequate net zero rating approach chosen for case study projects

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OUTPHIT – DEEP RETROFITS MADE FASTER, CHEAPER AND MORE RELIABLE
outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards.
outphit.eu

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SUMMARY

The outPHit project aims to support building owners and housing companies in performing reliable, quicker and more cost-effective deep retrofits. One element within this scope is a reliable and robust assessment of building concepts with regard to carbon emissions and the transition to renewable energy sources.

Often various flavours of “net-zero” concepts are discussed. Many times the definition remains fuzzy. Most suggestions relate to carbon emissions or annual balance of energy use and renewable energy yield of a renewable energy sources (RES) system on site. This approach generally has two major weaknesses:

For one, the energy use is not capped, meaning, that energy efficiency is not directly stipulated. It may or may not come into play indirectly but the annual turnover is effectively unlimited. This neglects the fact that the renewable energy (RE) potential is indeed constrained by natural limitations in available land. Since the energy transition is desired for the entire society and economy energy efficiency targets are indispensable to achieve the energy transition within the natural boundaries and economic constraints.

The other weakness relates to the two-fold temporal mismatch of abundant RES availability in the summer and reduced availability in the winter, due to reduced PV yield in this period, which is met by an increased energy demand in the winter due to space heating, particularly for inefficient buildings. The simple annual balance of e.g. PV yield and annual electricity usage is misleading as long as energy losses that are incurred in the processes involved to transfer electrical energy in time are not taken into account.

In order to establish a robust approach to guide design choices the Passive House Institute has developed the Primary Energy Renewable (PER) system. This system assumes the energy transition as accomplished and can thereby rate a building’s performance within a 100% RES scenario by way of weighting factors for energy use sectors. It makes the central assumption that electrical energy is the main primary energy available. The factors are derived from the proportions of immediate electricity use, required short-term storage (and its associated losses) as well as long-term, seasonal storage requirements (and its associated losses) as they can be expected for typical energy uses such as domestic hot water preparation, household electricity, space heating or space cooling.

In combination with a focus on energy efficiency such as inherent to the Passive House / EnerPHit schemes, a truly sustainable and robust solution can be identified, that will perform very well in today’s energy system while being 100 % ready for the all-renewable future.

INTRODUCTION

The transformation of the building stock towards a sustainable scenario for the future has many analogies to forestry: Sustainability originated there and means to think ahead for large periods of time and anticipate slow, but sure, developments. The central requirement is to plant today what is desired to be harvested two centuries later. Trees take many generations to grow and, similarly, buildings are very long-lived goods. Any changes in the building stock take place only very slowly, much investment is involved and much inertia needs to be overcome. This makes it even more important to design today what we would like the building stock to be in the desired future.

As far as retrofits are concerned there is another important aspect. Common sense dictates that any building refurbished now will not be refurbished again within the next five to ten decades. A zero fossil carbon economy is desired approximately for the year 2050, which is only some 25 years ahead. Hence, all refurbishments today must be optimised to perform well within the desired scenario of the future as there will not be an opportunity to alter them again.

In the future, the building stock shall be used sustainably. While this has some implications on building materials (see the outPHit deliverable D.4.3), the dominant factor is energy use. For a sustainable future, energy must be provided without carbon emissions and other hazardous substances.

However, renewable energy has another analogy to agriculture: It is available only in low density, spread across the country. As its potential is tied to the land on which it is harvested and the land is a finite commodity the renewable energy potential is also limited.

A discussion of different rating mechanisms of "net zero", settling on an adequate yardstick for the outPHit demonstration projects is required early on, in order to make informed and targeted design choices. A systematic disadvantage for apartment blocks with regard to single family homes must also be avoided, but is frequently implied in balancing PV yields from the available roof area with the gross electrical consumption. This naïve proportion is always more favourable in the case of low density structures while higher density structures (avoiding extremes such as skyscrapers) in fact offer great advantages in the use of resources of all kinds (land, heating energy, embodied carbon, public infrastructure, most times also energy spent on mobility, the viability of public transport, and more).

NET ZERO

In the past ten years various concepts have been proposed to achieve sustainability in buildings via different "net-zero" approaches. The use of buildings will invariably be tied to energy use in the 21st century, so a "zero energy use" scenario is ruled out from the beginning. The following paragraph tries a summarising overview of the "net zero x" approaches and discusses the most relevant pro's and con's respectively.

As a background to this discussion a brief description of the emerging future energy system shall be given first. Necessarily this will remain a very rough sketch and only a crystal ball could reveal any detail. It will, however, suffice to illustrate a few elemental dispositions that will characterise the situation with high probability, as they are rooted in physics and climate of the earth.

It is widely accepted that mitigating climate change requires to phase out fossil fuels quickly and to replace them with energy from renewable energy sources (RES). If nuclear energy is ruled out for its inherent catastrophic risks, nuclear weapons proliferation aspects, unclear long-term nuclear waste storage and cost any sustainable energy system of the future will thus be based on 100 % renewable energy (RE).

The availability of biomass is very limited and also competes with agricultural production for higher valued applications. It can only contribute a small fraction of the energy requirements in Europe, but has the natural benefit of being storable, which destines it for usage at times with low availability of other forms of renewable energy (dark calm in the winter). But it will also be much in demand as a chemical raw material or base for synthetic fuels of high energy density, as are required for airplanes and ships, which leaves even less potential for the building sector.

Hence, the primary energy of the future will be electricity from RES, mainly wind and photovoltaics (PV). Wind has slightly lower potential in the summer due to increased turbulence of the atmosphere at low heights above ground level. This is more than offset if enough PV capacity is installed (e.g. ~50/50). Combined, both sources can provide much power from spring to autumn. Pumped storage and batteries can be used to handle fluctuations on time scales of hours or days, transnational grid coupling helps in levelling regional fluctuations in the first place. In the winter, however, the PV potential in Europe is greatly reduced. A slightly increased wind power production cannot nearly offset this unless an uneconomic amount of wind power capacity were to be installed. The availability of suitable land limits the wind power capacity potential.

As a result, a structurally decreased availability of RE meets a structurally increased energy demand, caused by space heating requirements, in the winter. This challenge can be overcome by seasonal energy storage, transferring some of the summer's abundance of energy into the winter. Such seasonal energy storage can only be accomplished in chemical form, e.g. by electrolysis of water and storage of hydrogen or any derived compounds. These can then be re-converted into electricity at a later date, by fuel cells or thermal power plants. Waste heat from these processes can be useful, more heat can be generated from electrical power leveraged by heat pumps.

While these processes are readily available and the engineering behind them poses no material challenges they are characterised by a low roundtrip efficiency. Moreover, the installed capacity for power generation from seasonally stored energy carriers must be designed to deliver nearly the total grid load in the case of a dark calm but will operate at full load only for very short times. This is a substantial economic challenge.

As a result providing power at all times in the winter will require a substantially greater effort than in the summer or in the current situation. In a market based economy this will eventually articulate as a higher price for energy in the winter.

The above scenario suggests three obvious demands:

1. Use little energy in the winter: Avoid space heating demand as much as reasonably possible.
2. Use little power in the winter: Avoid spiking peak loads in order to limit the economically challenging backup power requirement from seasonal storage.
3. Keep the power grid stable and to keep the grid-build-up at a manageable level.

Rating concepts for the sustainability of buildings should not conflict with these demands and, despite all imponderabilities regarding the future, reliably steer today's design choices into the right direction.

Now we can start our little tour of the two major net zero concepts.

Net zero carbon

Claim: The world is challenged by a carbon problem, not an energy problem. Let's make carbon emissions the primary yardstick. Different forms of energy can be combined into a single figure representation by multiplication with their respective carbon emission factors before summing up.

Pro: Indeed climate change is driven mainly by carbon emissions and reducing or eliminating these as quickly and thoroughly as practically possible is of greatest importance.

Con: The approach will probably lead to the dangerous interpretation that substituting carbon-emitting ways of energy supply by carbon-neutral ways could lead to the desired goal, neglecting the limited availability of RE both spatially and temporally. The world does have an energy problem as well.

Discussion: If no other robust criteria are employed the net zero carbon approach will violate both demands of the future energy system. It does not limit energy or power use at any time of the year and thus fails to provide guidance towards the desired goal. Net zero carbon alone is clearly insufficient.

Moreover, the “net” can even allow residual fossil carbon emissions combined with offsetting schemes, an approach that is frequently criticized as inconsequent and dubious.

Zero carbon may have its merits as an additional criterion on top of any approach that meets both future energy system demands.

Net zero energy

Claim: The building produces as much or even more renewable energy as it consumes. A primary energy factor for generated and consumed energy can make both comparable.

Pro: Buildings occupy land and instead of using new land for RES it should be preferred to integrate RE capacity in buildings. As a regular measure it can help build the RES capacity the all-renewable energy system requires.

Con: It is not sound to balance summer energy abundance with winter energy requirements without taking the (seasonal) storage losses into account. These introduce an additional factor greater than 1 by which the summer generation must exceed the winter demand. Further, the grid must absorb great quantities of energy in the summer and provide great quantities of energy and power in the winter.

Discussion: If no other robust criteria are employed the net zero energy approach will violate both demands of the future energy system. The approach is at risk to offload its interaction with a future 100 % renewable energy system at the cost of the public spending on the seasonal energy storage and backup power system. Moreover, the approach favours low density forms of living that have severe disadvantages in terms of construction and land cost, urbanism, induced traffic, infrastructure investments etc. Factors for the rating of (non-renewable) primary energy lose their value as they require ever more frequent adjustments in a changing energy system. Within a 100 % renewable energy scenario they assume the value of zero and lose all of their guiding value. Net zero energy alone is clearly insufficient.

Net zero energy may have its merits as an additional criterion on top of any approach that meets both future energy system demands. A mechanism to avoid the preference for low-density structures must be devised in order to not stimulate a false optimisation.

100% RENEWABLE ENERGY

100% renewable energy is what is needed for the future. Some engineering advances will certainly be made, but the laws of physics and chemistry will always apply. This defines the framework for any possible solutions towards the energy system of the future. It will be safe to assume existing technology and not depend on developments that may or may not materialise.

One obvious element is the limited availability of land. Current discussions on wind turbine installations highlight this already. Much increase can still be made, but renewable energy will never be boundlessly available. What is more, it is naturally subject to short-term and seasonal fluctuations.

STORAGE REQUIREMENTS AND STORAGE LOSSES

Depending on the time scale different storage mechanisms come into consideration. For short-term storage ranging from a few hours to a few days concrete examples exist in the (mechanical) form of pumped storage (hydro and pressurised air). As pumped hydro storage depends on suitable terrain some research efforts are made to further develop the concept using underground cavities in combination with surface pools or subsea artificial cavities and sea water. Pressurised air storage would benefit thermodynamic optimisation if the compression heat were stored and reused upon expansion. Liquefied air storage is another flavour that does not depend on any geological conditions, but also poses the challenge of heat storage; it is very compact as the phase change from gaseous to liquid increases the density immensely but heat storage is the critical bottleneck for reasonable efficiency. The technologies in this field have essentially been well known for decades.

Battery storage is only emerging as a large scale grid stabilising component but many field tests are being made. The electrification of the transport sector will provide an ample supply of aged, but still useful, battery cells for stationary use. Further, exotic battery technologies such as redox-flow might prove useful in this field - total cost will be the critical factor. Battery storage does not depend on any topographical features and has no moving parts. It can be easily controlled by computers and reacts instantaneously. The technology is well known and will benefit from the determined research done for electric vehicles that have just seen their breakthrough.

For both short-term storage routes, however, losses cannot be avoided. Mechanical friction and electric resistance convert some of the energy into low-temperature heat that is no longer useful for technical purposes. This happens twice, at taking in as well as at reconversion to electricity. A safe assumption will be a round-trip efficiency of 70 %. As a result electricity via this path will be about one and a half times as expensive as electricity directly consumed at the time of harvesting. Since a major part of the electricity will still be available directly, short-term storage might be factored into a combined costing scheme.

Some storage capacity can also be activated in the form of heat in domestic hot water cylinders and building structures, and can be assumed as 95 % and 90 % efficient respectively: Excess electricity may be spent to heat up these capacities (using heat pumps) in order to avoid electric consumption at a later time with reduced availability of energy.

Long-term storage of electrical energy is economically viable only if converted to a storable chemical energy carrier. Electrolysis of water to hydrogen suggests itself as the basic process, the product might be further synthesised into more convenient compounds. Fischer-Tropsch synthesis may produce methane and longer chain hydrocarbons, but requires a suitable source of (non-fossil) carbon dioxide. Enriching atmospheric carbon dioxide (from ~0.04 % of the earth's atmosphere) requires much energy, harvesting it from the flue gases of burning biomass might lay the ground for a carbon recycling value chain in the future. Methane is the main constituent of natural gas and therefore may be directly fed into the existing infrastructure for storage, distribution and conversion. Methanol is another derivate that adds the advantage of being liquid at normal conditions, but also requires carbon dioxide. A way out of the ligand scarcity is the synthesis of ammonia, using nitrogen that presents 78 % of the earth's atmosphere and hence is very easy to obtain. Ammonia synthesis is a well-known, large scale industrial process (Haber-Bosch process) and ammonia may be stored at comparatively low pressure in liquid form, similar to liquefied petroleum gas (LPG) today. Direct, electrolytic ammonia synthesis from water and air is also possible and may offer improved efficiency in the future. Another advantage over methane is that ammonia has no global warming potential. The important downsides, however, are its toxicity and caustic/corrosive properties.

Assuming a conversion efficiency of 57 % for the conversion of electricity into methane is realistic. The re-conversion from gas into electricity in a CCTG plant may be modelled with an efficiency of 55 %. Electricity consumed via the seasonal storage therefore has an overall efficiency of *only approx. 31 %.* Finally, 5 % distribution losses must be considered for electricity transmission via the electrical grid. As a result electricity via this path will be about four times as expensive as electricity directly consumed at the time of harvesting, which might be beyond the limits of a combined costing scheme and be handed down to customers.

This brings back the two demands of the future energy system:

1. Use little energy in the winter.
2. Use little power in the winter.

Reducing the systematic winter energy supply gap by increased energy efficiency is a vital building block for an economically viable energy system based on 100 % RE.

PRIMARY ENERGY RENEWABLE

Different application sectors for energy in buildings have different temporal characteristics: Domestic hot water and plug loads will not differ very much over the course of the year, but heating and cooling/dehumidification are only seasonal in Europe. The regional climate determines the availability of renewable energy from wind and PV (and, to a lesser amount, the availability of hydropower) over time. It follows that any suitable rating system must take the temporal correlation of availability and demand into account, distinctly for each application sector and tied to the relevant local climate conditions. This has been modelled at the Passive House Institute comprehensively for locations worldwide.

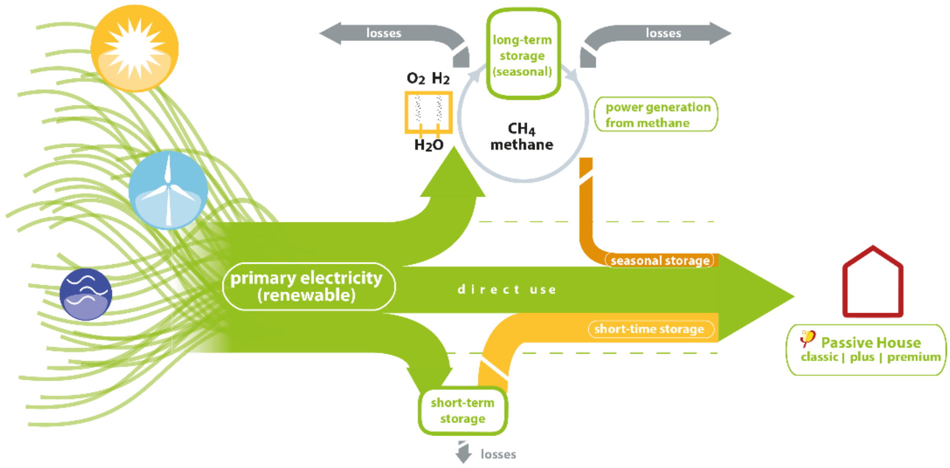

Figure 1: Sankey diagram of a future electrical power system based on all-renewable input from various sources, with short-term and long-term storage processes and associated losses

The modelled interaction of RES and energy demand in buildings yields factors greater than one that comprise all extra energy requirements to cover any losses in storage processes in order to meet the load curve of the respective sector. These application-specific factors that describe the incurred losses along the energy path from generation to storage and, finally, usage do not differ dramatically over fairly large areas. They can, for example, be unified for large regions and often even on a national level. The following table gives the Primary Energy Renewable (PER) factors for electricity in the outPHit partner countries.

PER factors for electricity in the EU [kWh/kWh]	AT	BG	DE	ES	FR	GR
General electricity	1.30	1.30	1.30	1.30	1.25	1.25
Domestic hot water	1.30	1.30	1.30	1.30	1.30	1.25
Space heating	1.80	1.70	1.80	1.70	1.70	1.75
Space cooling	1.10	1.10	1.10	1.10	1.05	1.25
Dehumidification	1.15	1.10	1.15	1.10	1.25	1.70

Table 1: Primary Energy Renewable (PER) factors for various electricity uses in the outPHit partner countries illustrate regional differences in Europe.

Obviously the largest factor is always related to heating, since the systematic gap of available RE and space heating demand must be covered from seasonal storage processes to a relatively large extent. Much more energy must be harvested in the summer to finally provide one unit energy for heating in the winter. For cooling the correlation of production and consumption is better, as PV yields are maximal in the summer and can easily cover cooling demand, with minimal storage for night times or cloudy days.

The PER system takes the critical effects on the grid level into account and provides a framework that steers today's design choices into the right direction. Together with an appropriate building standard, such as EnerPHit, that brings about stringent energy efficiency targets in combination with a PER limit, an optimal combination can be achieved.

Assuming the real grid to be transformed to 100 % RE over time, the buildings so rated will automatically also meet the zero fossil carbon emissions target which makes it largely dispensable on the level of an individual building.

The concept of the PER factors to rate energy use also already points to a sensible zero energy rating approach: A "net zero energy" building will provide as much energy as it consumes, taking into account all the energy system losses along the way in the form of PER factors.

But there was another objection: to not artificially favour low density structures. RES integration in buildings usually is PV panels on the roof. A large apartment block has much less roof are per unit living area than a bungalow. It is fair to demand to exploit the PV potential of any building, but it is also fair to acknowledge the less resource intensive living in large structures. Therefore, it makes sense to relate the PV yield to the footprint of the building, regardless of the height or volume or number of apartments. The footprint is intensely correlated with the available roof area for PV and can therefore present a readily available and sensible reference for the implemented PV capacity.

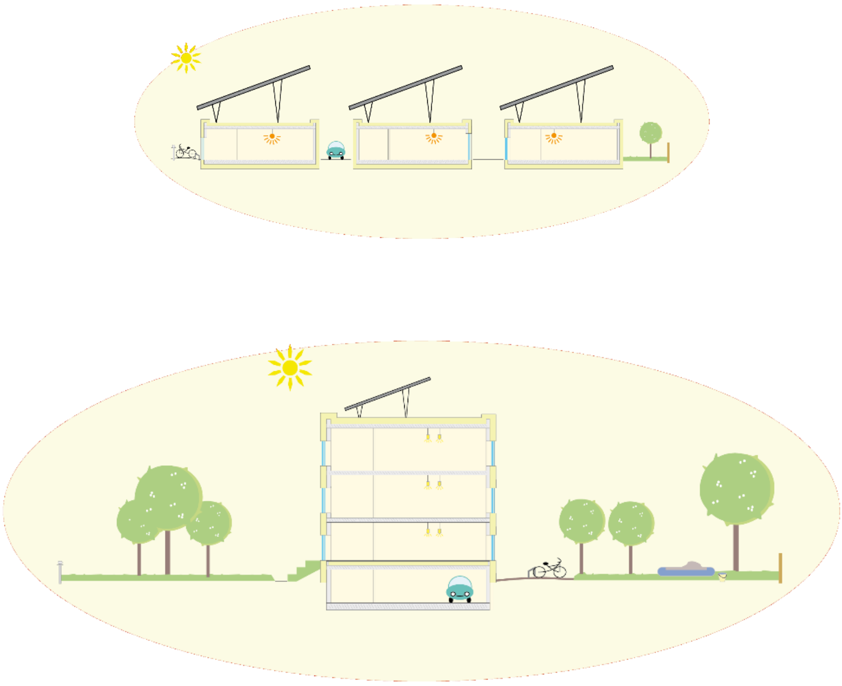

Figure 2: Rating PV implementation relative to the building footprint. In both situations the same useful space is provided. They differ in the space for the energy production, but have the same relation of energy production to building footprint, so the footprint-specific PER generation is identical. Assuming they have the same energy demands, their PER assessments will be the same.

It makes little sense but brings about the risk of expensive artefacts to stipulate more building integrated RES than can reasonably be implemented on the roof, particularly in the refurbishment context. If additional potential on facades is also accessible with little extra effort such can be incentivised with a “plus” or “premium” rating.

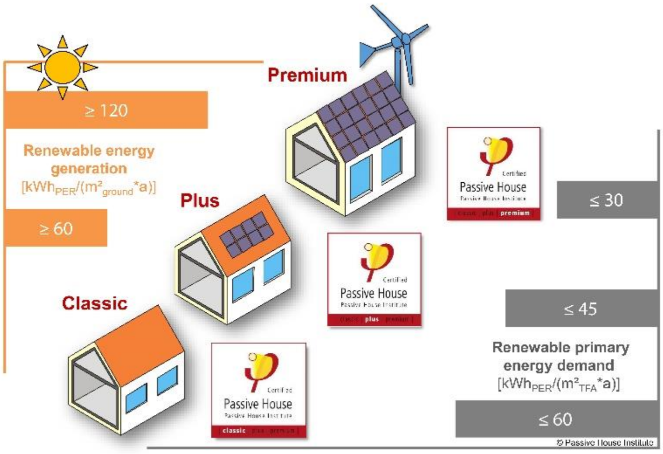

Figure 3: PER rating of energy efficient buildings, taking RE yields into account. Both energy efficiency and RE harvest are optimised in their own right. The same scheme applies to the EnerPHit refurbishment standard used in outPHit.

CONCLUSION

The Passive House and EnerPHit efficiency-oriented building standards combined with the PER rating approach for demand and RES yield in relation to the building footprint overcomes the weaknesses of other net zero carbon and net zero energy rating schemes.

Energy demand in the critical winter period is minimised in the first place. Also the peak power requirement for space heating in such buildings is minimised, due to the very good thermal insulation and high time constant. The demands for seasonal storage capacity and for re-conversion installed power are both minimised.

Buildings designed and rated against this framework will perform perfectly within an all-renewable energy system of the future and contribute to reducing the burden on the power grid already today.

Fossil carbon emissions are minimised instantly as much less energy is consumed. With the transition of the energy system towards 100 % RES a zero carbon status will be achieved.

The procedures are easy to handle by designers, simple rating factors take up existing schemes based on non-renewable primary energy factors.

An adequate yardstick for the RES implementation on site is available, with reference made to the footprint of the building. The scheme does not incentivise, but also not penalise, low density forms of living.

Newly installed RES as per the “plus” or “premium” building class requirements will instantly contribute to the energy transition as far as feasible on-site.

REFERENCES AND FURTHER READING

(click the links)

The PER concept

Details on the PER assessment

Background on simulation to derive PER factors

PHI Building Certification Guide