

Technological Potential for Zero or Low Carbon (ZLC) - Energy Options in the UK Building Sector

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Abstract: *The UK Government is committed to developing a sustainable energy economy in the 21st Century, and to taking a lead in reducing carbon dioxide (CO₂) emissions amongst the industrialised (OECD) countries. An aspirational target of reducing these emissions to 60% of their existing figure by 2050 has been adopted. The only way in which this fall could be achieved is by significantly reducing primary energy consumption to between 45-75% of the present demand; depending on the energy supply technology mix (fossil fuels, nuclear power, or renewable energy technologies). This will require the widespread adoption of energy-saving measures across the economy that would necessitate action by many individual stakeholders. In the domestic sector, where buildings contributes around 30% of final energy demand and some 23% of greenhouse gas emissions, the uptake of zero or low carbon (ZLC) technologies may play an important role in CO₂ abatement. Several of these technologies have been assessed in terms of their techno-economic feasibility. They have included solar hot water heaters, solar photovoltaic panels, small-scale wind turbines, and ground source heat pumps. Investment appraisal of these micro-generators indicates that they are presently uncompetitive under current UK liberalised market conditions, even with the aid of government grants. Improvements in the next generation of ZLC technologies, their manufacturing processes, and production volumes are necessary in order to lower their capital costs. Only then will they be economic in comparison with separate supply via the electricity or natural gas networks, enabling them to deliver their undoubted environmental benefits.*

Keywords: Distributed Energy Resources, Micro-generators, Zero or Low Carbon Technologies, UK Building Sector, Energy Demand Reduction, Energy Efficiency, Technology Assessment, Investment Appraisal

1. INTRODUCTION

The United Kingdom (UK) government, like many around the world, is committed to reducing its carbon dioxide (CO₂) emissions. Not only have they signed up to the Kyoto treaty, but they have set more stringent domestic goals over the longer term. Their aim, set out in their 2003 Energy White Paper, is a 60% reduction in CO₂ emissions by 2050. This would require significant reductions in primary energy consumption, and the adoption of cleaner technologies. Buildings in the domestic sector represent large consumers of energy. The adoption of zero or low carbon (ZLC) technologies would therefore help to reduce its emissions from this sector. However, the technology potential and economics of such options need to be evaluated. Distributed energy resources (DERs), or micro-generators, like solar hot water heaters, solar photovoltaic (PV) cells, small-scale wind turbines, and ground source heat pumps (GSHP) are all potential candidates for ZLC systems. But, in accordance with the so-called ‘energy hierarchy’, energy efficiency and demand reduction ([1], [2]) should be implemented before embarking upon the use of micro-generators. Householders, for example, could save energy by the adoption of thermal insulation measures (including draft proofing, cavity wall insulation, and double glazing), better control of central heating systems, and the adoption of low-energy behavioural patterns (as such the purchase of energy efficient appliances, low energy light bulbs, and turning off electronics or avoiding standby). All these have been shown to be cost-effective in terms of carbon saved per monetary unit invested. The resulting ‘low-energy’ heat and power load profiles should then be used to determine the potential role of DERs.

2. METHODOLOGY

In order to assess the ability of various micro-generators to meet the demands of British domestic dwellings, the load profiles for five separate building types were initially modelled. These reflected a variety of dwellings that are typical of the UK domestic housing stock. They were: detached, semi-detached, and terraced houses, an apartment, and a bungalow. Characteristic layouts for each building type were devised [3], together with four different levels of thermal insulation. The latter insulation levels corresponded to past (late 1970s) building standards [4], current standards [5], best practice [6], and advanced levels [6]. Different occupancy levels were also prescribed for each type of building. That gave rise to variations in appliance use that was used to estimate the electrical load of each property. The different combinations of dwellings, and lights and appliances, gave an indication of the differing energy requirements across the domestic sector, and providing a range of energy demands that micro-generators would be required to satisfy. A computer model was created in order to aid the analysis, with the ‘benchmark’ case taken to be a detached house located in Bath, England [7]. It was a 3 bed (detached) house with a floor area of 89 sqm (m²), and was occupied by 2 adults with two dependent children. The roof pitch was 45°, with an azimuth of 5°. The house utilised natural gas for heating, and had best practice insulation levels as recommended by the UK Government’s *Energy Saving Trust* (EST). These ‘best practice’ insulation levels exceeded those specified in the most recent UK 2006 Building Regulations Part L. Each DER - solar hot water heaters, photovoltaic (PV) cells, small-scale wind turbines, and ground source heat pumps (GSHP) - was then assessed for its techno-economic feasibility in a domestic building context assuming grid-tied systems.

A financial investment appraisal of the micro-generators was undertaken assuming a zero discount rate, rather than the rate currently recommended by Her Majesty’s (HM) Treasury of 3.5% for public investments in the UK [8]. There is no reason to think that the rate at which firms and householders actually discount the future represents the rate at which society as a whole should discount it [9]. Society may put a higher value on future resources than either individual consumers or companies. Firms, for

example, will tend to consume natural resources faster than is justified for society as a whole. Munby (1976) [10] even argued that in the case of depleting fossil fuels a negative discount rate might be appropriate (although, in practice, this has not been used). It is certainly clear that discounted cash flow (DCF) techniques of investment appraisal, with their short-term focus, do not adequately reflect resource depletion: fossil fuels will be more valuable to society in the future (when they have been depleted) than they are at the present time. The life of each DER was assumed to be 20 years. Some micro-generators may last longer, for example solar systems of various sorts may survive for more than 30 years, but 20 years was considered to be reasonable lifetime in the absence of real life data on these new technologies.

3. RESULTS AND DISCUSSION

3.1 Household Energy Requirements

In a detached house with 1978 insulation levels the space heating load was found to be almost 28,000 kWh. When the insulation levels were upgraded to correspond with the most recent 2006 UK Building Regulations (Part L), the energy consumption attributed to space heating was reduced to 14,700 kWh. This represented a significant saving over a property insulated to late 1970s standard. Nevertheless, the 2006 UK building standards do not push the technological boundaries far enough to satisfy UK longer-term carbon dioxide abatement targets. The EST best practice insulation levels, the ‘benchmark’ case adopted for the present study, reduced the heating demand to just over 11,300 kWh (see also Fig. 1). It is possible to go even further, for example, by upgrading to the EST ‘advanced’ level. Under these conditions the detached house would consume just about 5,700 kWh on heating per annum; representing almost an 80% reduction in energy consumption over 1978 standards. If the UK is to achieve a 60% reduction in its CO₂ emissions by 2050, then an improvement to something like this level is clearly desirable.

The load profile for the benchmark case was modelled not only in terms of its space heating requirement, but included hot water and electricity consumption. The resulting balance between space heating, hot water usage, and lighting and appliances is depicted in Fig. 1. The electricity consumption was initially estimated to be 4,900 kWh per annum, but when embarking upon the installation of a DER option, it is desirable to start by reducing energy demand reduction. A low energy profile should therefore be used to size micro-generators. Electricity consumption could be reduced to around 3,660 kWh with the aid of energy saving light bulbs (which consume only 20% of the energy of traditional light bulbs) and the purchase of the most energy-efficient appliances. ‘Greening’ of consumer habits was not explicitly considered in the present study, because it was largely outside of the scope of an assessment of micro-generators. But it is possible, of course, for environmentally-conscious householders to significantly reduce their energy demand via lifestyle changes. The benchmark space heating demand was predicted to be 11,343 kWh per annum, with a hot water requirement corresponding to 5,000 kWh. Thus, the total energy demand was almost 20,000 kWh of delivered energy as illustrated in Fig. 1.

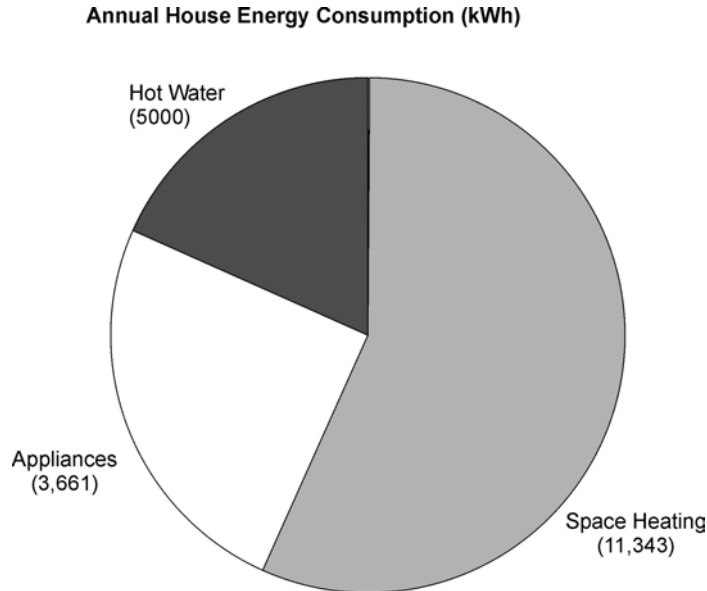


Fig. 1 Energy Budget for the Benchmark Case – Detached House with UK *Energy Savings Trust's* ‘Best Practice’ Insulation Levels

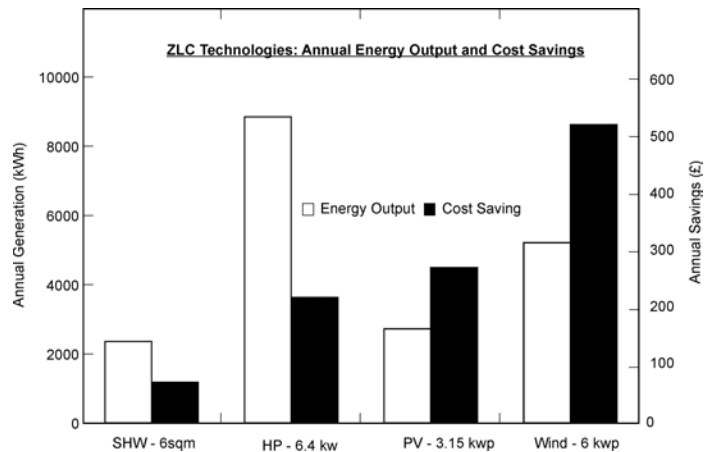


Fig. 2 Annual Energy Output and Cost Savings Associated with the Micro-generators [SHW – solar hot water; HP - ground source heat pump; PV – solar photovoltaic cells; and Wind – small-scale wind turbine]

3.2 The Distributed Energy Resources

The energy output and the associated monetary savings of the solar hot water (SHW), solar photovoltaic (PV) system, ground source heat pump, and wind turbine are displayed in Fig. 2. Many British homes could benefit from the use of a solar hot water system that will see a small saving each year (over natural gas central heating). The SHW system analysed in the present study was a 6 sqm (m²) flat plate collector with an assumed total system efficiency (including the losses in the pipes, storage tank and conversion efficiency of the collector plate) of 34%. This system had an annual output of over 2,300 kWh which equals almost 47% of annual demand; sufficient to meet 100% of summer demand. In the winter months, this would need to be supplemented by an immersion heater. The monetary value of the energy saved per year due to the SHW system was equal to £70 per annum over natural gas central heating. This reflects the relatively low price of natural gas compared with other forms of energy. If the natural gas system was to replace an electric or oil heating system, then the saving would be higher (unless a so-called 'Economy 7' electricity tariff was not in operation).

Solar PV cells are presently the most expensive form of ZLC technology, although they attract UK Government installation grants, which are considerably more generous than for other DERs. These grants typically amount to 50% of the installation costs. However, the UK still falls behind other Northern European countries, such as Germany, in the number of PV installations. The system analysed here had a capacity of 3.15 kWp, which was predicted to produce over 2,700 kWh and lead to a saving of £270 per annum on energy bills. The corresponding full system capital cost was estimated to be £16,300. One advantage of PV cells was that they generate electricity, which has a high quality (or 'exergy') energy resource [1], and can be utilised for both heat and power applications.

Successful harnessing of the wind, via small-scale turbines, relies upon the nature of the localised terrain and siting of the building. The turbines assessed in the present study were designed to be mounted directly to a building, but this in itself is a less than ideal way of capturing wind as the siting of the turbine is restricted to the land of the homeowner, in urban locations the quality of the wind will be affected by turbulence caused by the surrounding structures. For this reason a capacity factor of 10% was assumed for the purpose of this study, although some owners in an ideal rural location and with a high wind quality may be able to double the output compared with this analysis. Small-scale wind turbines cannot achieve the same capacity factors as their larger counterparts. Large turbines have a high hub height, which give it access to a high wind speed and shear. A 6 kWp wind turbine was assessed in the present study, which was estimated to generate 5,250 kWh of electricity per annum. Again the electricity generated can be employed in domestic buildings to partially satisfy heat and power requirements.

Ground source heat pumps (GSHP) are the most efficient form of heat pump technology, but they require a very large area in which to lay ground loops. They are thus more suited to rural areas, where a natural gas supply is sometimes not available and to new build dwellings, if an under-floor heating system is integrated into the design of the house, and not considered as a direct cost of a GSHP, then payback periods are obviously more favourable. It is also more economical to install the ground loops at the time of construction. These loops comprise of lengths of piping buried in the ground, either in a borehole or a horizontal trench. The pipe is normally a closed circuit filled with a mixture of water and antifreeze, which is circulated around the loops/pipe in order to absorb heat from the ground. Typically a GSHP can achieve a Coefficient of Performance (COP) of 3-4 [11], which means the system will produce 3-4 times as much heat as the input energy required to operate the pump itself. It was assumed that an 'Economy 7' tariff was used to operate the GSHP to lower the operation cost. This is the name of a tariff provided by UK electricity distributors, which uses base load generation to provide cheap night-time electricity. The GSHP considered here was rated as a 6.4 kW unit.

3.3 Financial Investment Appraisal

The Net Present Value (NPV) of the micro-generators was analysed after 20 years of operation. Fig. 3 displays the NPV results of the investment appraisal with a zero discount rate. ZLC technologies may be eligible for grants in the UK that cover a proportion of the initial system costs (for domestic use). Presently this scheme is known as the 'Low Carbon Buildings Programme' (LCBP), which is managed on behalf of the UK Government by the EST. The systems were analysed with and without the award of such

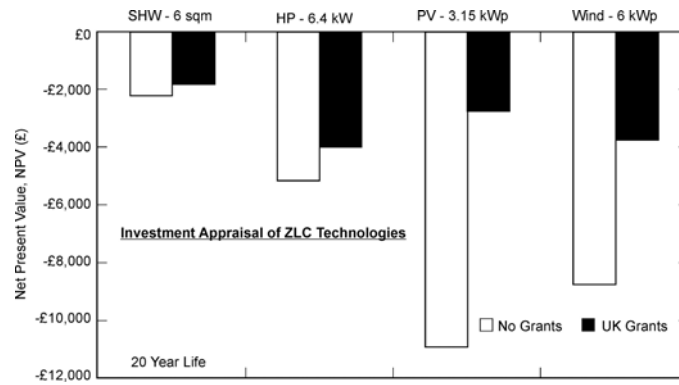


Fig. 3 Net Present Value of Micro-generators; Zero Discount Rate and 20 Year Life [SHW – solar hot water; HP – ground source heat pump; PV – solar photovoltaic cells; and Wind – small-scale wind turbine]

micro-generation grants (see Fig 3).

None of the analysed systems paid back over 20 years, the solar hot water system had an NPV of almost -£2,200 without LCBP grants, falling to -£1,800 with the award a micro-generation grant. Fig. 4 shows the amount of money lost per kWh of energy generated (again for systems with and without LCBP grants). In the case of the SHW system, 4.7 p/kWh was lost per kWh without a LCBP grant, reducing to 3.8 p/kWh with such a grant. This is not the cost of energy generation, but represents the amount of money lost per kWh of energy generated over the current natural gas energy supply. Clearly, the likely variability of fossil fuel prices over the 20 year analysis period will influence the current economic findings. It might be possible for the SHW system to last for more than 30 years. Over this time period, and if fossil fuel prices experienced large increases, then the economics of SHW systems may improve considerably. Some environmentally-oriented consumers may consider losses of the type indicated above to be acceptable, compared with the environmental benefits of reducing CO₂ emissions. It was estimated that the SHW system will save a tonne of CO₂ per annum.

The ground source heat pump had an estimated 20 year NPV of -£5,150 without a micro-generation grant, reducing to -£3,950 (see Fig. 3) with such grants. This equates to a loss of 2.9 p/kWh (Fig. 4) reducing to 2.2 p/kWh with LCBP grants supplementing the capital costs. This level of loss may be acceptable to a range of householders, and may even be favourable if replacing an electric or oil heating system. However, this appraisal has neglected the installation cost of under floor heating, and the ground loops in the garden. The installation cost of under floor heating was estimated to be in the region of £4,000, which would have a detrimental effect upon the economic analysis.

The solar PV system gives rise to an adverse NPV of almost -£10,900 falling to -£2,730 when LCBP grants were applicable (see Fig 3). The corresponding loss per kWh was estimated at 19.8 p/kWh in the former case, and 5.0 p/kWh in the latter (Fig. 4). PV currently represents an expensive investment, but if a dwelling is situated in a remote location, then it may be more economical than paying to secure a grid connection. Solar PV operates out of seasonal phase with wind turbines. Consequently, when the two technologies are coupled, they may provide a means of ensuring a stable, year round, energy supply.

The micro-wind turbine assessed here, rated at just over 6 kWp output, had a 20 year NPV of -£8,700 without LCBP grants reducing to -£3,700 with grants (Fig 3). The money lost per unit electricity generated was 8.3 p/kWh without a micro-generation

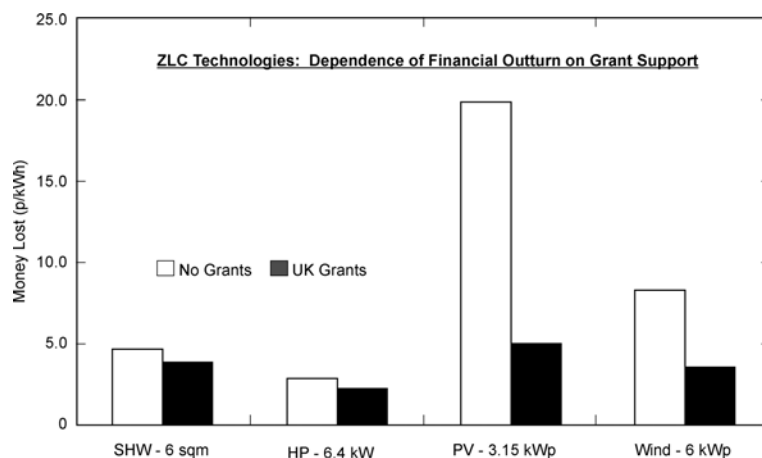


Fig. 4 Financial Outturn for Micro-generators; Zero Discount Rate and 20 Year Life [SHW – solar hot water; HP – ground source heat pump; PV – solar photovoltaic cells; and Wind – small-scale wind turbine]

grant, reducing to 3.5 p/kWh with EST grant support (see Fig. 4). Wind has the advantage of generally being in phase with peak demand in the UK climate, partially due to the large heating load in the winter. The wind is typically strongest during colder months; therefore the peak output from the turbine will help to satisfy this peak demand.

3.4 Discussion

Micro-generators offer a way of reducing the CO₂ emissions, but before embarking upon the ZLC route demand reduction is the desired course of action in line with the principal of the ‘energy hierarchy’. This could be achieved through improvements in insulation levels, double glazing, energy saving light bulbs or energy saving appliances. If DER options are not going to be considered, then modern heating equipment, such as condensing boilers, could offer both energy and carbon savings over a traditional boiler. If more homeowners could be persuaded to take seriously an energy efficiency and demand reduction measures, then not only will CO₂ be saved, but the energy consumption will be lowered and hence the lifetime of current reserves would be extended.

In the liberalised energy market in the UK, ZLC technologies cannot compete with separate, grid-connected supply. But in the long-term, micro-generators have the added advantage that they, unlike fossil fuel dominated separate supply, are a sustainable energy resource. This gives them important long-term environmental prospects. The adoption of DERs not only saves CO₂, but also ‘cushions’ the householder against fluctuations in fuel prices. However, before micro-generators become truly competitive, substantial investments will be required in micro-generation technologies to improve their operation efficiencies and reduce manufacturing costs. When this happens, mass production will induce ‘economies of scale’ that will reduce manufacturing costs. The timescale over which that might happen is open to doubt. But increases in the prices of depleting fossil fuels are likely to be the principal driver for change in the domestic energy sector.

The various ZLC technologies have been analysed assuming typical weather data for Bath in the UK. The results for these micro-generators in different climates (and with other countries having different grant schemes) would vary, and would need to be re-analysed under case-specific conditions. The capacity factor for micro-wind turbines was assumed to be 10%, but it is possible that some owners would be able to achieve a capacity factor of 15% for micro-wind generation. This would yield an extra 50% output, and brighten the financial results considerably. Over 20 years the full NPV becomes -£3,500, but with the award of LCBP grants of about £5,000, the NPV would rise to show a profit of £1,500, 3.4 tonnes of CO₂ would also be saved per annum. The UK has excellent wind resources, and as such it might be anticipated that some houses could achieve a capacity factor above 10%.

Distributed energy resources, although currently uncompetitive, could offer benefits to developing countries where poor infrastructure favours a stand alone (battery) system. A remote community could benefit through a solar PV system or micro-wind turbine providing its basic needs. Under such circumstances fossil fuels may not be the most appropriate; they require constant supplies of energy and a continual operational cost (fuel) which are subject to fluctuations. If for some reason fuel was unable to be delivered then the community would have no energy and even though some ZLC technologies have intermittent sources (wind, sun) in certain climates the resources are fairly reliable, i.e. PV near the equator or balance a PV system with a wind turbine.

4. CONCLUDING REMARKS

The UK domestic building sector, which contributes around 30% of final energy demand, and around 23% of greenhouse gas emissions, can play an important role in CO₂ abatement. An uptake of zero or low carbon (ZLC) technologies, sometimes referred to as distributed energy resources (DERs) or micro-generators, would help this sector to reduce energy use and CO₂ emissions. Technologies such solar hot water (SHW) heaters, photovoltaic (PV) cells, small-scale wind turbines, and ground source heat pumps (GSHP), are all likely candidates. Energy efficiency and demand reduction ([1], [2]) should be implemented before embarking upon the use of these micro-generators. For example, householders could save energy by the adoption of thermal insulation measures (including draft proofing), low-energy consumption patterns (energy efficient appliances, low energy light bulbs, and by turning electronics off and avoiding standby), and better control of central heating systems. Once implemented the low-energy load profiles should be used to determine the role that distributed energy resources (DERs) can take. The economics and technology potential of such schemes have been evaluated.

Investment appraisal of these micro-generators (under the most favourable case of a zero discount rate) indicates that they are presently uncompetitive under current UK liberalised market conditions, even with the aid of government grants. Improvements in next generation ZLC technologies, their manufacturing processes, and production volumes are necessary in order to lower their capital costs. Only then will they be economic in comparison with separate supply via the electricity or natural gas networks, enabling them to deliver their undoubted environmental benefits. The domestic sector can make more than a 65% reduction in CO₂ emissions by 2050 without any degradation of the quality of life, provided that urgent action is taken now [12].

Many British homes could benefit from the use of a solar hot water system that will see a small saving each year (over gas heating). However, the payback period is over 20 years even with a UK Government grant to aid in the purchase. Ground source heat pumps (GSHP) are the most efficient form of heat pump technology, but they require a very large area in which to lay ground loops. They are thus more suited to rural areas, where a natural gas supply may not be available. If an under-floor heating system is integrated into the design of the house, and not considered as a cost of a GSHP, then payback periods are likely to be more favourable. PV cells generating electricity are presently the most expensive form of micro-generation, although they attract UK LCBP installation grants which are considerably more generous than for other ZLC technologies. These typically amount to 50% of the installation costs. Successful harnessing of the wind, via small-scale turbines, relies upon the nature of the localised terrain and siting of the building. The turbines assessed in the present study were designed to be mounted directly to a building, but this in itself is a less than ideal way of capturing wind. Nevertheless, even assuming a capacity factor of 10%, wind generation proved to

be an attractive option for CO₂ reduction; especially in comparison to the other DER options evaluated.

The techno-economic potential of domestic-scale combined heat and power (micro-CHP) systems was not analysed in the current study. However, they are likely to offer significant CO₂ savings in the future. This technology is in its infancy in the UK, and field trials are ongoing. If the economics prove favourable, and the technical issues related to operating a highly distributed network can be solved, then it may prove to be an effective low carbon technology; one that is not carbon free, but has the potential to save CO₂ of average householders.

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The authors' names appear alphabetically.

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