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BRE National Solar Centre Client Report

Building Integrated Photovoltaics

Prepared for: The Ekinoid Project

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1 Description of the Project

1.1 Description of the project

This document aims to explore the potential for solar PV as a primary source of energy generation for the Ekinoid concept home. One of the key goals of the Ekinoid home is not only fully energy self-sufficient but also putting excess electricity into the local grid: via the use of a Vertical Axis Wind Turbine on the roof and/or by extensive use of solar panels. This document aims to explore some of the solar PV technology options currently available for an Ekinoid home, including an evaluation of off-grid storage systems, which could be used to help make an Ekinoid home self-sufficient.

1.2 Description of the NSC

The BRE NSC provides a technical, trusted and independent voice for industry and consumers. The NSC supports enterprises throughout Cornwall and the Isles of Scilly engaged with the solar industry. This document is the outcome of the free support offered, which constitutes as two days consultancy.

2 Document Structure

2.1 Building integrated photovoltaics

This section covers a brief introduction to types of Building integrated photovoltaics (BIPV) currently available on the market.

2.2 Traditional solar PV technologies

This section includes an introduction for alternatives to BIPV such as traditional frame mounted solar PV systems and ground-mounted PV systems.

2.3 Off-grid storage

This section gives a brief overview of the considerations for off-grid storage mechanisms, discussing key components and considerations for an Ekinoid home to be fully energy independent.

2.4 Discussion

This final section evaluates the options available to the Ekinoid Project.

3 Introduction

One of the key goals of the Ekinoid home is for it to be completely self-sustaining for its energy needs; this means that it will require renewable energy sufficient to meet that demand. Small-scale wind is not considered economical on a domestic basis, with small-scale turbines largely proven to be inefficient and on occasion, have caused damage to the buildings they are mounted on. Consequently, solar has emerged as a much more popular technology on the domestic scale and is increasingly common in the UK domestic energy market. Solar has a number of significant benefits compared to small-scale wind notably, that the technology has no moving parts making it very low maintenance and the ability to integrate it into a building envelope, without compromising the fabric of that building. This document aims to determine the potential for solar PV to be incorporated onto and into the fabric of the Ekinoid home.

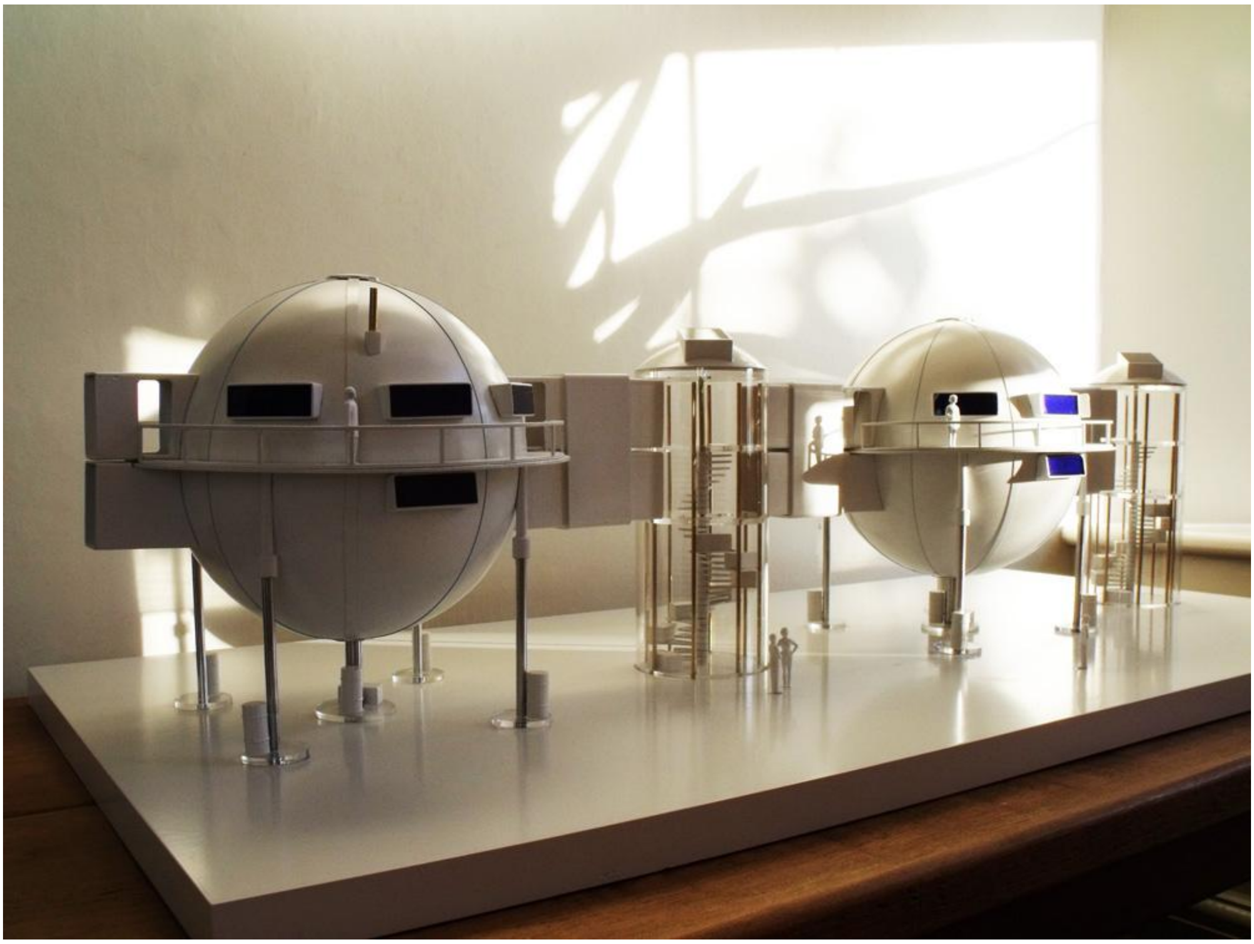

Figure 1: Ekinoid 3D printer model

4 Building integrated photovoltaics

There is a rapidly growing market for onsite, renewable generation of electricity due to rising consumer energy prices (~6% per annum for electricity) this trend is likely to accelerate given global energy supply and energy security issues. The aesthetics of energy generation play a crucial role in its effective role out. The renewables sector, particularly solar, is looking to improve the visual impact of these vital technologies.

Figure 2: Solar Slates

Over the past few years the installation of standard, rectangular crystalline modules has rocketed due to incentives such as the government's Feed-in Tariff scheme. These 'one-size fits all' system designs are sometimes perceived to detract from the elegance of the surface they were put upon. The BIPV market looks to integrate photovoltaics seamlessly into the fabric of a building and as an industry, is rapidly increasing in the UK with predictions of a 2.4 GW stake by 2016.

The Ekinoid house is a perfect candidate for the bespoke nature of building integrated photovoltaics. There are a myriad of technologies to be considered as detailed below. The BRE National Solar Centre **does not** endorse any of the companies mentioned above; they are examples for information only.

4.1 Solar Tiles

Saint-Gobain recently pushed the limits of design by producing an original, diamond-shaped array of solar tiles, as shown in Figure 3 below. Rather than being situated one next to the other in a parallel arrangement, the modules overlap each other with one corner pointing down and one up. The photovoltaic tiles are attached to the underlying load bearing structure using especially designed watertight fixings. Edging tiles are then used to ensure a clean finish.

Figure 3: Diamond shaped solar tiles

Another company offers Solar Slates (Figure 2, above). These simple tiles are the most commonplace example of building integrated PV in the domestic market and have been used favourably by the National Trust in the refurbishment of their historic buildings. The slates are wired individually and together. The slates are installed in the same way as normal roof slates and compliment the appearance of traditional, quarried slate tiles. These may suit the Ekinoid homes as an outer layer if the homes are to be covered in tiles.

4.2 CIGS Technology

The Solar Cloth Company uses CIGS technology in flexible solar ‘strips’ that can be adhered to a plethora of surfaces. Figure 4 shows an example of a Solar Cloth installation. The spectrum absorbed by mono/poly/amorphous silicon cells ranges from 400-700 nm, while the absorption range for CIGS cells is from 300-1300 nm. This means that CIGS modules outperform silicon cells during low light, cloudy or hazy conditions. They are less dependent on direct sun radiation or the position of the sun in order to function.

Furthermore, CIGS modules do not degrade in efficiency over time at the same rate as amorphous silicon, the efficiency of CIGS panels is may even increase in the first few days of “sun soaking”.

Many of the installations of this type of technology are over tensile membranes such as stadiums and marquees but they can be installed with ease onto surfaces ranging from curved roofs to flat lorry tops. These solar ‘strips’ could be used to wrap around the Ekinoid modules as they are less dependent on the orientation to the sun.

Figure 4: Solar cloth installation

4.3 Transparent Cells

Transparent or translucent cells are comparatively inefficient but the technology is becoming a popular alternative to façades and windows. A Spanish company, Onyx offer transparent glass at 10, 20 or 30 % transparency depending on the requirements for daylight below.

Figure 5: Transparent solar PV cells

They have also recently patented translucent coloured PV glass. Such technology could be used in the central stairwells of the Ekinioid buildings without obscuring too much of the light.

Figure 5 shows an example of 30% transparent solar glass.

4.4 Coloured Cells

Translucent orange panels from Polysolar were the choice for Sainsbury's PV-covered fuel courts in Dorset and Hampshire in 2013. These glass module have recently been adapted into green house roofs and conservatories across the country. Figure 6 shows an example of coloured solar cells.

Oxford PV, a spin-off Photovoltaics Company from Oxford University won the Renewable Energy World Award for innovation in 2011 for their coloured, translucent dye-sensitized solar panels. Dye-sensitized and quantum-dot sensitised solar cells are predominantly in the research phases and not yet commercially viable.

Figure 6: Coloured solar cells

4.5 White solar cells

CSEM a private non-profit Swiss company have developed a coating which makes solar panels white. This is a unique technology as white surfaces are generally thought to reflect most of the usable light for solar panels. There is likely to be a certain amount of efficiency loss from the solar panel, on account of some of the usable spectrum being removed by the coating.

It can be applied on top of an existing module or integrated into a new module during assembly, on flat or curved surfaces. It can be used to change the colour of all existing panels or create customized looks from the onset.

White solar cells would be easily integrated into the Ekinoid structure and would blend in well with the remainder of the structure if the façade is coloured white, as models suggest.

Figure 7 shows the CSEM white solar PV module. This technologies is still in the earlier stages of development, however, will be commercially available over the next few years.

Figure 7: CSEM white solar module

4.6 Opaque Cells

Integrating opaque solar cells into safety or laminated glass brings possibilities to architects to design modules that fit the shapes, measurements and location of a building without compromising on the efficiency. Their designs often allow for holes in the cells themselves to let more light through for walkways, ceiling and windows. The cells can come in different colours but are generally opaque.

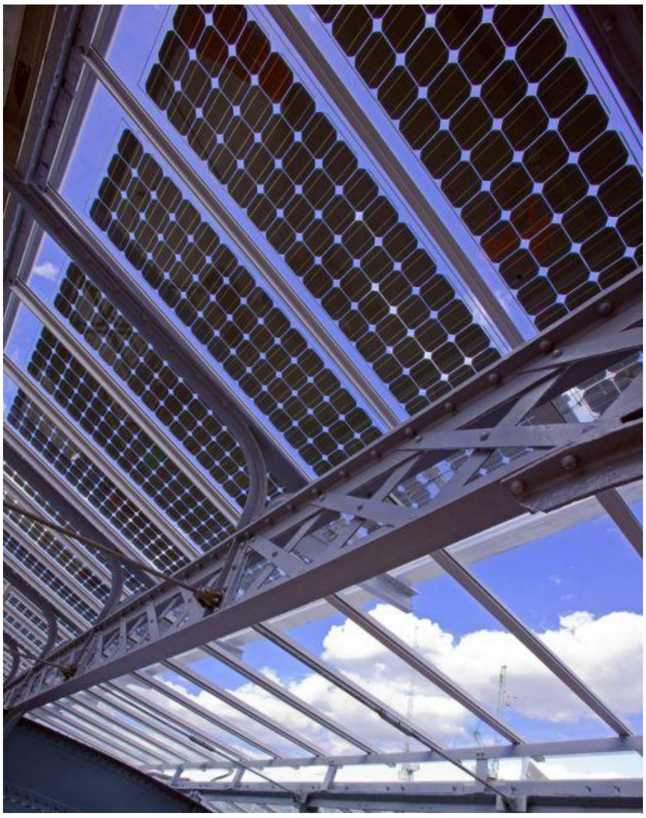

Figure 8: Opaque solar cells

Sundog was responsible for the design, supply and electrical installation of possibly the largest and most complex BIPV system in the UK to date on kings cross railway station. The project utilized 1,392 bespoke glass laminate units designed and supplied by UK-based glass specialist Romag. Along with the logistical complexity of installing the overhead glass roofing structure whilst the station was in daily use, the aesthetics of the system were also critical as the station is a Grade I listed building. See Figure 8.

4.7 Polygonal modules

Treleigh House near Redruth in Cornwall is a stunning example of triangular, rectangular and trapezoidal PV panels. The modules were installed onto the southern elevation of a property in an "area of outstanding natural beauty" at the coastal location in Cornwall. The Solar panels were designed to complement the natural slate on the northern roof.

Figure 10: Treleigh House

The same company, GB-Sol also offer the UK's first terracotta-coloured cells for facades and show several examples of triangular modules in other locations.

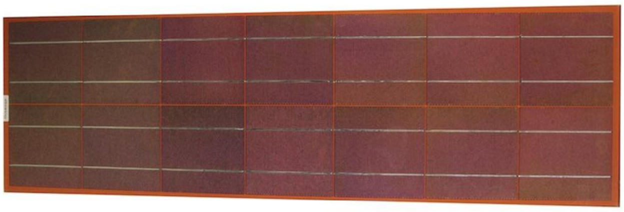

Figure 9: GB-Sol terracotta module

5 Alternatives to BIPV

5.1 Traditional frame mounted solar PV systems

An alternative to the potentially costly building integrated solar PV technologies is to install roof mounted solar PV on an appropriate surface of the Ekinoid homestead.

Traditional, frame mounted PV systems constitute the majority of the current UK installed capacity.

Frame mounted solar PV generally uses crystalline silicon cell technology. This technology tends to be more efficient than many similar technologies because the technology is more technologically advanced, than many competitor roof integrated technologies.

Figure 11: Frame mounted rooftop system

Exterior mounted solar PV can be aesthetically obtrusive and may not be an ideal candidate for the curved surfaces of the Ekinoid home, however, they are the cheapest currently available on the UK market.

Because of the shape of the Ekinoid home the spaces available for normal frame mounted solar PV technologies are limited to the roof of the walkway and the roof of the stairwell.

5.2 Ground mounted solar PV systems

Another option is to have a frame mounted solar PV system separate to the building. This uses traditional solar silicon based solar PV modules (the same as those used on traditional roof-mounted solar PV systems) mounted on a standalone frame on the ground.

Figure 12: Ground mounted solar PV system

Mounting a solar PV array in this way has a number of benefits. Firstly, the free movement of a large volume of air ventilates the panels which can get very hot in direct sunlight. The efficiency of solar photovoltaics reduces by 1% for every 1C of heating so keeping the system cool improves the generation. Secondly, the design of the mounting system is not restricted by the orientation of a roof or façade but can be set at an optimum pitch to allow for maximum productivity. Thirdly, the installation is not limited by the availability of space on a building. In order to sustain itself as an off-grid system Ekinoid will need a sizable array to meet demand.

By using the most technologically advanced modules on the market and having the freedom to position them at optimum orientation and angle, ground mounted will yield the greatest generation output for Ekinoid homes.

6 Available space for solar PV development on Ekinoid

6.1 The surface of the sphere

The outside surface area of the sphere is 358 m^2 however, you would only use the top half of the structure, on account of the bottom being shaded and only the south facing side would be worth installing the technology on as the north face would also be too heavily shaded; leaving 90 m^2 suitable for solar PV. The overall circumference of 32.5 m and the segregation of the roof surface into 8 sections mean the widest point of each section is around 4 m. This means that is all of the space was utilised the top of each of the 4 segments on the south side could accommodate around 500 W of solar collectors each. However; factoring in the space the windows occupy. The south sided roof segments could only accommodate around 2 kWp in total.

The spherical nature of the Ekinoid home limits the choice of solar PV technologies that could be installed on it. Flexible CISGs modules may be best suited for installation onto the surface of the sphere because they have the flexibility to bond securely onto curved surfaces.

6.2 The roof of the stairwell and walkway

The two roof spaces which could readily accommodate traditional silicon based solar PV technologies are the stairwell and walkway roofs. The top of the stairwell could accommodate around 1.5 kWp and the walkway roof could accommodate around 1 kWp of traditional silicon based solar PV modules.

6.3 The glass of the stairwell

The stairwell has a cylindrical glass exterior. One of the design criteria of the Ekinoid home is that it the stairwell is used as a hydroponic greenhouse, to provide food stuffs for the inhabitants. Research carried out by Akira Nagashima in Japan showed that around 32% of sunlight can be taken from crops without adversely affecting their productivity (Movellan, 2013). This means that some kind of solar glass could be used whilst still using the stairwell for growing crops.

Transparent and coloured solar PV technologies could be used instead of traditional glazing for this area. The transparent lends itself best to the application as it would have the lowest effect on the hydroponic farming activities. Alternatively the CIGS or opaque cells could be used and be designed such that no more than 32% of the surface area is covered in solar PV technology.

6.4 The external walkway around the perimeter of the sphere

The walkway around the external perimeter of the Ekinoid home could accommodate BIPV. This space could accommodate around 9 traditional solar PV panels which would equate to around 2.25 kWp of PV generating capacity.

This external perimeter could be used to provide a protective barrier for people whilst generating electricity. Depending on the main criteria regarding transparency, either traditional frame mounted PV technologies could be used, or a more aesthetically pleasing solution could be found using the transparent cells, coloured cells or small opaque cells similar to those in Figure 13.

7 Off-Grid Energy Storage

Off-grid properties are becoming increasingly popular. Battery storage and inverter technologies are now being designed specifically to accommodate to this kind of arrangement. Some of the advantages of having a renewable energy powered, off-grid system is that you do not have to pay for a single unit you consume, you are not affected by power outages in the national grid and you will not be affected by the increasing cost of grid electricity

7.1 Components of an off-grid energy system

7.1.1 Energy generation sources

This document focusses on solar as a renewable energy source however, there are other technologies that would complement such as system, such as small scale wind or hydro. These technologies could be called upon when the sun is not shining brightly. That said, solar PV should be considered as the most suitable generation technology for the Ekinoid home as it is the most predictable and the least likely to go wrong, there are also numerous surfaces of the building that can be accommodate solar technology.

7.1.2 Battery

Batteries are a key component of an off-grid system, storing the energy generated for later use, but are also one of the most costly. Advances in battery technology mean that new technologies are developing all of the time. Lead acid batteries are still used in the majority of off-grid systems because they are one of the cheaper technologies and relatively easy to manage in comparison to others. Lead acid batteries take up a significant amount of space and so sometimes more lightweight solutions such as lithium ion batteries are more appropriate.

Batteries have a finite lifetime, with a well-designed battery bank only being expected to last around 10 years depending on the design and exact technology choice. Replacement of the battery bank would need to be considered by the householder.

7.1.3 Battery charger

Batteries are difficult to manage and need specifically configured equipment to ensure safe operation. The battery charger controls the voltage going into the battery bank, whilst also modifying the voltages of the batteries themselves to prevent the batteries coming to harm.

7.1.4 Inverter

The inverter takes the output from the battery bank and converts it to the correct voltage for household consumption, this is 240 V in the instance of the UK electricity network but may vary depending on where the Ekinoid home is situated. By using an inverter the Ekinoid occupants can use normal off-the-shelf appliances around the household.

7.2 System Sizing

Based on an annual consumption for an Ekinoid home of 3000 kWh, which is a little below the average of 3300 kWh for a UK domestic household. The battery bank would need to be around 2500 amp hours (Ah). You would then need a minimum of a 4 kWp solar PV system, this PV system to be the primary energy source of the building, however, a larger system is likely to be preferable, as it will reduce the risk of long overcast periods fully discharging the battery bank.

7.3 Costing

An off-grid system would require an investment of around £3000 for batteries, the PV system will cost around £7000, the inverter-battery charger will cost around £2000, the control system will cost around £500 and all the other components such as cabling are likely to cost in the region of £1000. This all comes to a total of £13,500 which may seem expensive, but over a 20 year lifetime of the technology would only cost around £700 per year to provide all of the household’s electricity.

8 Discussion

Solar energy should be considered the primary renewable electricity generation source for the Ekinoid home as it offers significant benefits in comparison to other technologies. The outputs from solar are largely predictable, the technology is comparatively low maintenance and it can be readily incorporated onto a building, around or even become part of the fabric of the building itself in order to generate electricity for the occupants.

BIPV is an emerging market with an increasing range of solutions ready and commercially available. As the recent Kings Cross BIPV installation showed, there is huge public interest in BIPV and a desire to understand how it can work as a component of a building as opposed to an add-on. Traditional solar PV technologies are added onto the existing fabric of a building however, BIPV comes out of the desire to more effectively incorporate solar technologies into the building envelope be that facades, roof lights or louvers.

Figure 13 on the following page is an example of an effective BIPV façade that does not inhibit the use of the space inside. In doing this BIPV reduces the weight and resource requirements usually associated with solar PV technologies. This is in keeping with one of the Ekinoid project’s key goal of reducing the weight and resource required to develop a sustainable home.

Figure 13: Showing BIPV glass replacement installation

There is a wide range of BIPV technologies which could work as part of the Ekinoid home. Together, the highest, south facing area of the sphere; the roof of the stairwell; the joining walkways and the façade perimeter walkway yield around 6.75 kWp of total solar generation capacity. The stairwell glass could also be built from transparent solar glass however, it is impossible to accurately ascertain how much capacity this would give as the efficiency varies greatly from technology to technology. The above details are based on today's technology options, new innovations are emerging on a regular basis.

The modular nature of the Ekinoid home seems to lend itself well to being off the mainstream electricity network, as this would give the building the autonomy it has in so many other aspects of its design. To do this it would require a relatively complex off-grid battery storage system as detailed in the previous sections of this document. There are some significant advantages to being off-grid such as being less susceptible to power outages in the electricity network and the ability to insulate yourself against the inevitable rise in energy prices. Off-grid electricity systems are expensive and do require an amount of user engagement to keep them working properly. Off-grid electricity systems are also very specific to the user and so a bespoke design for each potential occupant would be required to ensure a system is fit for purpose.

Report Ends

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