

## SOLAR INTEGRATION ON COMMERCIAL BUILDINGS

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**Abstract** – Commercial high-rise buildings use up to 30% of all electrical energy from Australia's power grid. This is a major contributor to Australia's greenhouse gas emissions and fossil fuel use. Forrester Kurts, currently developing a 21 storey commercial building at 120 Edward Street in the Brisbane CBD realised the economic, environmental and marketing advantages in showcasing building integrated solar and cost effective improvements in building energy consumption. The design philosophy was to reduce the use of energy and produce green electricity to offset the need for polluting coal generated electricity. This paper discusses the Solar Integration System proposed to be installed at a 21 story commercial development at 120 Edward Street, Brisbane, Queensland. The project will contribute to the transformation of the photovoltaic industry in Australia through the resolution of design issues for roof and glazing solar building products suitable for a commercial development. In addition the project is determining the market's interest in novel power conditioning solutions aimed at reducing the cost of converting the solar DC output to useful AC power.

### 1. INTRODUCTION

Commercial high-rise buildings use up to 30% of all electrical energy from Australia's power grid. This is a major contributor to Australia's greenhouse gas emissions and fossil fuel use. Forrester Kurts Developers, a major commercial property developer, is preparing to construct a 21 storey building at 120 Edward Street in the Brisbane CBD. Forrester Kurts realised the economic, environmental and marketing advantages in showcasing building integrated solar and cost effective improvements in building energy consumption. The design philosophy was to reduce the use of energy and produce green electricity to offset the need for polluting coal generated electricity.

To determine the potential for energy reductions and encourage the efficient use of electricity the Queensland Environmental Protection Authority funded Integrated Energy Services to review the building's energy services. HASSELL, the project architects, were set the challenge of designing a roof form suitable for the incorporation of solar panels to generate green electricity. Subsequently, Forrester Kurts, HASSELL and Integrated Energy Services were successful in securing \$740,000 from the federal government's Australian Greenhouse Office (AGO) to meet the additional costs of weatherising the solar roof.

### 2. ECONOMIC SETTING

The commercial acceptance of building integrated solar will ultimately be driven by price and not concern for the environment. With the price from standalone grid connected solar projects in the order of 70 to 95 cents/kWh, versus 8 to 12 cents/kWh for grid electricity, it is clear that of solar electricity needs to fall substantially to be a real choice for building developers.

The Solar Integration System developed for the 120 Edward Street commercial building will provide solar electricity at a delivered cost of 20-30 cents/kWh. The economic competitiveness of solar is expected to increase further still in the future with the predicted fall in the price of photovoltaic (PV) cells over the next 3-5 years.

### 3. SOLAR INTEGRATION SYSTEM

The commercial high-rise at 120 Edward Street incorporates an 80kW<sub>p</sub> building integrated PV system. An Australian first, the Solar Integration System demonstrates the commercial potential of building integrated PV. The PV's DC power output is converted to AC power ready for use by the building's tenants through the use of an "off-the-shelf" uninterruptible power supply (UPS) system. The UPS output will be on-sold to building tenants to provide a "secure" supply for sensitive computer equipment. The UPS is provided on a commercial basis by the developer and allows the PV power conditioning to be provided at zero cost to the project. The system has been designed by Integrated Energy Services winners of a 1996 National Energy Award for innovation in use of PV in remote areas.

#### 3.1 Solar System Design

The system's solar structure includes approximately 50kW<sub>p</sub> of amorphous silicon photovoltaic structural roofing panels integrated into the main roof. A further 30kW<sub>p</sub> of 12mm laminated glass with 100 watt per square metre polycrystalline laminates provides shading on the 21<sup>st</sup> and 19<sup>th</sup> floors, as well as the atrium roof at ground floor.

The power conditioning unit includes a 120kVA inverter with a maximum power point tracker. The inverter nominated for the project has a trade price that is 33% lower than currently available dedicated solar inverters, thus significantly reducing power conditioning costs. The value added power use will be marketed to building tenants as a green power service. The marketing of the service is in its preliminary stages, however, initial indications are that building tenants are showing strong interest in being able to buy green power as part of the leasing options.

### 4. BUILDING INTEGRATION KEY TO COST SAVINGS

120 Edward Street aims to provide substantial reductions in the cost of solar power generation through the use of a fully integrated design concept. Prior to identifying opportunities for solar cost savings, the cost of traditional solar needs to be fully understood. Electricity cost analyses are presented below.

#### 4.1 Cost Analysis – Traditional Solar

| COST ANALYSIS                              |                    |                 |                 |
|--|--------------------|-----------------|-----------------|
| ELECTRICITY PRODUCTION – TRADITIONAL SOLAR |                    |                 |                 |
|  | Item               | Upper Cost/Watt | Lower Cost/Watt |
| COSTS                                      |                    |                 |                 |
|  | Solar Panels       | \$5.00          | \$4.50          |
|  | Framing & Support  | \$2.00          | \$1.50          |
|  | Wiring             | \$0.50          | \$0.50          |
|  | Power Conditioning | \$0.50          | \$0.40          |
|  | Total              | \$8.00          | \$6.90          |
| OFFSETS                                    |                    |                 |                 |

|          |                  |               |               |
|----------|------------------|---------------|---------------|
|          | Roofing material | \$2.50        | \$2.00        |
|          | Roof Support     | \$1.50        | \$2.00        |
|          | UPS Service      | \$0.50        | \$0.40        |
|          | Total            | \$4.50        | \$4.40        |
| NET COST |                  |               |               |
|          | <b>Total</b>     | <b>\$3.50</b> | <b>\$2.50</b> |

To compare the cost of grid supplied electricity with solar, the capital cost of solar electricity needs to be converted to a cents per kilowatt hour equivalent. This is achieved through the following formula.

$$\text{Solar}_{\text{Cents/kWh}} = \frac{[(\text{Solar}_{\text{CapX}} + \text{Solar}_{\text{OpX}}) / \{\text{Solar}_{\text{Power}} * \text{Losses}_{\text{Cable}} * \text{Losses}_{\text{Heat}} * \text{Losses}_{\text{Match}} * \text{Losses}_{\text{Conversion}}\}]}{}$$

- Solar<sub>Cents/kWh</sub> = cost of kilowatt hour of solar electricity based in current dollars
- Solar<sub>CapX</sub> = Annutised capital payment to repay capital investment over life of project while returning a rate of return on the investment.
- Solar<sub>OpX</sub> = Annual maintenance cost of solar power system.
- Solar<sub>Power</sub> = Annual kW hour of electricity generation from 1 kW solar array
- Losses<sub>Cable</sub> = cable losses of DC and AC wiring in percentage terms
- Losses<sub>Heat</sub> = losses of solar panel based on heat build of panel
- Losses<sub>Match</sub> = losses associated with mismatch of PI curve of solar to actual load
- Losses<sub>Conversion</sub> = losses in conversion of solar DC power to AC power.

Example calculation: -

- Solar<sub>CapX</sub> = \$8.00 per installed peak solar watt.
- Solar<sub>PanelsCapX</sub> = \$5.00 per installed peak solar watt.
- Solar<sub>OpX</sub> = 2% of capital costs.
- Solar<sub>Power</sub> = 1825
- Losses<sub>Cable</sub> = 5%
- Losses<sub>Heat</sub> = 20%
- Losses<sub>Match</sub> = 10%
- Losses<sub>Conversion</sub> = 7%
- Return on Investment = 10%
- Project Life = 20 years

$$\text{Solar}_{\text{Cents/kWh}} = [(940+160) / \{1865 * 0.95 * 0.8 * 0.9 * 0.93\}] = 1100 / 1160 = \$0.95$$

#### 4.2 Cost Analysis – Building Integrated Solar

Using the same method to calculate the unit cost as used for the traditional solar, the cost to generate electricity from solar installed under the Solar Integration System with a capital cost of \$2.50 - \$3.50 per watt is 23.5 – 32.9 cents/kWh.

Predictions are that the cost of PV will be in the range of \$2.50 - \$3.50 per watt with 3-5 years compared to current prices of \$5.00 per watt. The impact of this is presented in the following table.

**COST ANALYSIS**  
**ELECTRICITY PRODUCTION – BUILDING INTEGRATED SOLAR**

|                 | Item               | Upper Cost/Watt | Lower Cost/Watt |
|-----------------|--------------------|-----------------|-----------------|
| <b>COSTS</b>    |                    |                 |                 |
|                 | Solar Panels       | \$3.50          | \$2.50          |
|                 | Framing & Support  | \$2.00          | \$1.50          |
|                 | Wiring             | \$0.50          | \$0.50          |
|                 | Power Conditioning | \$0.50          | \$0.40          |
|                 | Total              | \$6.50          | \$4.90          |
| <b>OFFSETS</b>  |                    |                 |                 |
|                 | Roofing material   | \$2.50          | \$2.50          |
|                 | Roof Support       | \$1.50          | \$1.50          |
|                 | UPS Service        | \$0.50          | \$0.40          |
|                 | Total              | \$4.50          | \$4.40          |
| <b>NET COST</b> |                    |                 |                 |
|                 | <b>Total</b>       | <b>\$2.00</b>   | <b>\$0.50</b>   |

Using the same method to calculate the unit cost as for traditional solar, the cost to generate electricity from solar installed under the Solar Integration System with lower cost PV is 4.7 - 9.4 cents/kWh.

Through smart integration of solar power systems cost reductions in the order of 60% are attainable. Cost reductions to achieve this may be obtained through building integration and cost reductions of power conditioning and framing. The Solar Integration System designed for 120 Edward Street aims to provide economical solar electricity, ultimately at zero cost power conditioning and framing costs.

## 5. ARCHITECTURAL DESIGN CONSIDERATIONS

The story of 120 Edward Street involves strategic positioning and economic design in a very tight market which has not seen a new high rise office building in a decade. The architecture has driven the energy conscious design process. HASSELL, being committed to the rational use of resources, introduced the notion of low energy design and solar power generation to the project. The approach was adopted partly for life cycle cost benefits but primarily for marketing benefits, essentially creating a point of difference for the project. Unfortunately the delivery of major buildings fights against design innovation and reasonable design outcomes.

Generally, buildings are delivered by developers who have no interest in the long term ownership and operation of a building. The long term owners are usually institutions which are more interested in security and safety for their investors than issues such as energy conservation. There are of course benefits in rational design for the long term owners of buildings but to educate them and the industry is the real challenge. We believe 120 Edward Street will help to demonstrate the benefits of energy conscious design to the development and investment industry.

The consulting process also fights against innovation. Low fees do not create the most inventive environment. It is only professional interest and pride that drives consultants. The current economic circumstances involves fee targets, budgeted hours and performance indicators, all unheard of in the 1980's but all essential. Without an interest or perhaps the fee/time in improving the performance of buildings, old technology, proven, simple to design, virtually fool-proof, possibly even over designed is the easy solution which is economic to deliver.

In Queensland where no high rise office buildings have been delivered in a decade, proven technology is the technology of the 1980's, which is based on the 1970's design. Over the last 5 to 10 years we have also seen changes in accommodation standards and expectations. From the excesses of the 1980's we have seen the space per person reduce from over 20m<sup>2</sup> per person to 12m<sup>2</sup> per person and less. Accordingly, lifts that were designed for almost half the building population of today can no longer provide the level of service expected. Similarly, the services in older buildings have also been stretched to the limit as the building population has increased.

For example, air conditioning systems can not cope, cabling requirements can not easily be accommodated and communications riser are inadequate for the multiple suppliers, tenant cabling between floors and secure risers. Additionally, VDU dependence requires glare free lighting and the control of natural light. Working in 1980's buildings and experiencing a generational shift in the way business is done has resulted in more sophisticated tenants who understand the key issues which impact on their comfort and the way they do business. This to a large extent has driven Forrester Kurts, the developer of 120 Edward Street, to encourage all those involved in the project to question commonly accepted standards including:

- office layout;
- space requirements;
- services;
- fire and smoke requirements;
- construction techniques;
- fitout and churn requirements;
- cost effectiveness; and
- energy consumption, passive control systems and energy generation.

This approach has proven successful resulting in:

- Federal, State and Local government support;
- growing national and international interest in the project; and
- tenants wanting to embrace energy conscious design (without paying more for the privilege).

Accordingly, every decision to improve the energy performance of the building was tested against traditional energy solutions to determine the cost benefits and pay back periods.

Energy consumption takes many forms in buildings:

- in the manufacture of materials, usually referred to as "embodied energy";
- in the transportation of materials, "grey energy";
- in the construction of the building, "induced energy"; and
- "operating energy", which obviously relates to running costs.

Embodied energy, grey energy and induced energy all impact on construction cost and therefore, are largely dealt with through delivering a building economically. Through the traditional property delivery process only high technological solutions are acceptable. "Green" low impact building solutions are not feasible. Only advances through technology are acceptable in the marketplace in our view. For example, no air conditioning in sub-tropical Brisbane would be unacceptable but night purge and economic cycles are feasible, though difficult to physically accommodate. The major energy costs in modern offices in our climate relate to air conditioning and then lighting. These were our primary concerns in the design of the building.

Simply, 120 Edward Street is a modest 20 storey commercial building which incorporates cost effective and practical energy saving and energy generation systems. The solar performance of the building for example was critical to the low energy design solution.

- Orientation was determined to minimise heat gain and glare.
- Glare and heat gain were limited through the use of sunshades and high performance, but economical glass.
- Sunshading was computer modelled with the building design evaluated insitu within the CBD. An innovative glazed sunshade / second skin was designed for the western façade but was rejected on cost grounds in favour of fixed sunshades, high performance glass, double glazing (primarily to limit noise), higher window sills (ie., 600mm rather than 450mm above floor level).

This balanced and rigorous process will lead to an economical solution which will achieve the energy savings referred to in this paper. The expression of the building is simple with little overt evidence of the design innovations. The building has a masonry frame with punched windows but a glazed curtain wall to maximise the view for tenants. The static sunshading devices will be obvious and the large overhanging roof will be a powerful statement of the energy generation capabilities. The roof will extend over the boundary and be seen from both roads and hence become the signature for 120 Edward Street. The edge of the roof will have laminated clear glass and photovoltaic cells which will be edge lit at night to create a glowing halo.

Clear glass photovoltaic laminated panels will also be used on a glazed roof near the entry through which the entire building will be visible. We are also investigating the use of solar energy to drive a sculpture near the entrance or to animate the walls to the above ground carpark. We may even see a solar powered traffic light near the main entry to the building!

The entire design team is committed to delivering 120 Edward Street. Everyone knows that to achieve sensible design requires a champion or champions, vigilance and persistence. Forrester Kurts are driving it for commercial and marketing reasons; HASSELL has consistently championed rational design; the services consultants, building surveyor and contractor have worked together to ensure the best possible outcome; and Integrated Energy Services has provided the technical knowledge, economic advice and enthusiasm to ensure the services engineers design and document systems are compatible with our joint objectives.

## **6. ENERGY EFFICIENCY AND ENERGY MANAGEMENT**

In conjunction with the design and implementation of the Solar Integration System, energy efficiency and management were seen as areas for additional cost savings. A detailed review of all building service systems was undertaken to ensure that energy used in delivering of building services was as efficient as possible. The advanced energy systems recommended will provide:

- Return of 21.1% to Forrester Kurts on \$1M additional capital investment in energy and water efficiency technologies.
- Reductions of 1,640 tonnes of CO<sub>2</sub> per annum.
- Estimated operating cost savings of \$214,000 per annum.

- Based on the current concept design, the building qualifies for a 5-star SEDA greenhouse rating, becoming one of the first commercial buildings in Australia to achieve such a rating.

Initiatives recommended in the review include passive design principles such as night purge and economiser cycles. Additional active system features include the energy management system bringing floors on line with air conditioning only as tenants for that floor enter the lift lobby and CO<sub>2</sub> sensors on fresh air supply fans and duct pressure controlling supply fan speeds.

## 7. CONCLUSIONS

This paper has demonstrated that building integrated solar can deliver both economical and environmental benefits.

| SUMMARY COST ANALYSIS<br>ELECTRICITY PRODUCTION               |                     |
|---|---------------------|
| Electricity Generation  | Cost<br>(Cents/kWh) |
| Coal  | 8 – 12              |
| Stand Alone Solar   | 70 – 95             |
| Solar Integration (current)                                   | 20 – 30             |
| Solar Integration (predicted)<br>(\$2.50/Watt<PV Cost<\$3.50) | 5-10                |

Ongoing reductions in solar electricity depend upon the development of cost effective solar building products, economical power conditioning equipment and suitable and efficient 'end-users' of the solar electricity produced. Cost reductions of around 65% are achievable today when comparing building integrated solar to standalone solar. Future cost reductions as high as 85% are predicted within the next five years, making building integrated solar a truly competitive option for commercial developers.

## REFERENCES

Exergy Group Pty Limited (1999) Greenhouse Rating Scheme Methodology.