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Procedia Engineering 00 (2017) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

# Assessment of potential energy and greenhouse gas savings in the commercial building sector by using solar energy for air-conditioning purposes

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## Abstract

Australia currently faces significant increases in electricity prices. The owners and occupants of buildings are influenced by this change and alternative technologies are being investigated to reduce outgoing costs. The adoption of renewable and alternate solar technologies is gaining favour as reductions in technology component prices occur. The increase in population density and societies increasing expectation of conditioning spaces requires the continued investment in air-conditioning plant and equipment, generally at the expense of greenhouse gas emissions and high electricity consumption. This paper reviews the current potential of energy and greenhouse gas savings by using alternative solar-energy technologies for air-conditioning in commercial buildings. The economics of solar thermal and solar photovoltaic cooling systems will be discussed by calculation of the Levelised Cost of Cooling (LCOC) i.e. $/kWh of cooling. The paper will conclude the economic viability of solar thermal cooling in 2015 and provide comparison to findings based on 2011 economics to demonstrate the improving financial viability of solar-energy usage for air-conditioning. The paper further outlines constraints for adoption of solar thermal cooling in the commercial market and provides predictions on the potential greenhouse gas emissions savings that can be achieved from the adoption of alternate energy sources for air-conditioning.

*Keywords:* Solar Cooling; Solar Air-Conditioning; Solar Thermal Cooling; Solar Electric Cooling; Solar Thermal Air-Conditioning; LCCE

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## 1. Introduction

Solar cooling and solar air-conditioning are generic terms for a process that uses solar energy to drive a cooling or refrigeration process. Two commercially available solar cooling technologies exist: solar thermal and solar-electric cooling.

Solar thermal cooling systems utilise heat from the sun as the main driving source for a cooling or refrigeration process. These technologies include absorption, adsorption, desiccant-evaporative, ejector and liquid sorption cooling. On average, these systems require approx. 50% less electrical energy than conventional vapour-compression systems. Solar thermal systems are available ‘off-the-shelf’ and are a mature technology. The technology has been proven feasible worldwide but global sales are still orders of magnitude lower than of conventional cooling/refrigeration systems.

Solar electric cooling is to combine photovoltaic panels with a vapour-compression cooling or refrigeration system and to use the electricity generated from the sun, not the heat. It is possible to use the electricity generated from photovoltaic (PV) modules directly in a vapour-compression chiller, e.g. via a direct power cable link between PV generator and chiller. However, more often these solar electric systems are used based on an annual balance, where the annual electrical energy required by the chiller is covered by the annual PV power generation. This means there are times during the year where the actual PV power is not sufficient to cover the momentary chiller power demand (hence additional grid power is being drawn by the chiller).

It is estimated that the installed base of non-residential air-conditioning systems in Australia [6]:

- Consumes 9 per cent of electricity produced in Australia, representing more than 3.6 per cent of Australia's greenhouse gas emissions.
- Creates more than 55 per cent of electrical peak demand in commercial business district (CBD) buildings.
- Consumes billions of litres of water per annum in cooling towers.
- Is part of an industry worth $7 billion per annum that employs more than 95,000 people.

Residential systems have not been investigated in this paper. Cost figures on residential solar cooling systems can be found in [1]. Economies of scale make larger units more economic and the hours of operation are usually much greater in an industrial/commercial application compared to residential. At the time of writing this paper approx. 1,200 solar thermal cooling systems have been installed globally, with the majority of those operating in Europe [2].

## 2. Methodology

The air-conditioning, cooling and refrigeration markets in the states of Australia differ significantly from each other. The climatic differences across Australia result in solar applications having quite variable annual outputs. The approach of this paper is to compare solar thermal versus solar electric cooling in a commercial air-conditioning application; hence a location had to be chosen where both solar resource and air-conditioning demand are of suitable magnitude. The city of Sydney was chosen for this purpose. Three air-conditioning systems have been compared:

A. Solar thermal parabolic trough collectors and a double-effect absorption chiller (STAC)
B. Photovoltaic panels and a scroll type vapour-compression chiller (PVAC)
C. Reference case: Grid-connected scroll type vapour-compression chiller (REF)

The systems are illustrated in Fig. 1 to Fig. 3.

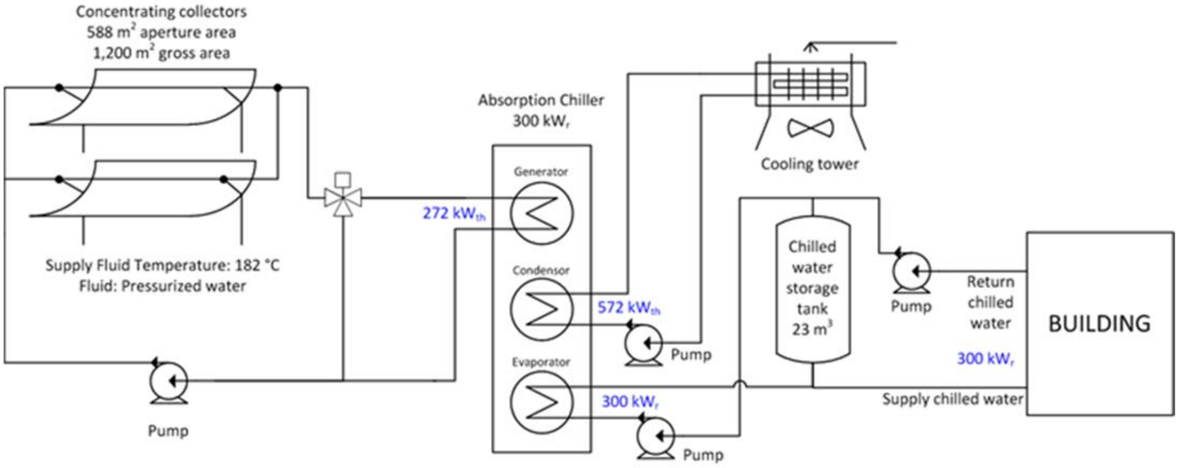

Fig. 1. System schematic of solar thermal A/C system (STAC)

The solar thermal system (STAC) uses parabolic trough collectors with an annual average efficiency of 40% and a peak efficiency of 58%. A chilled water storage tank of 23,000 litres is used as a buffer tank. The absorption chiller is a water-cooled double-effect chiller with an annual average COP of 1.1. The solar thermal system yield has been calculated using Meteonorm data for the climate zone of NSW [3].

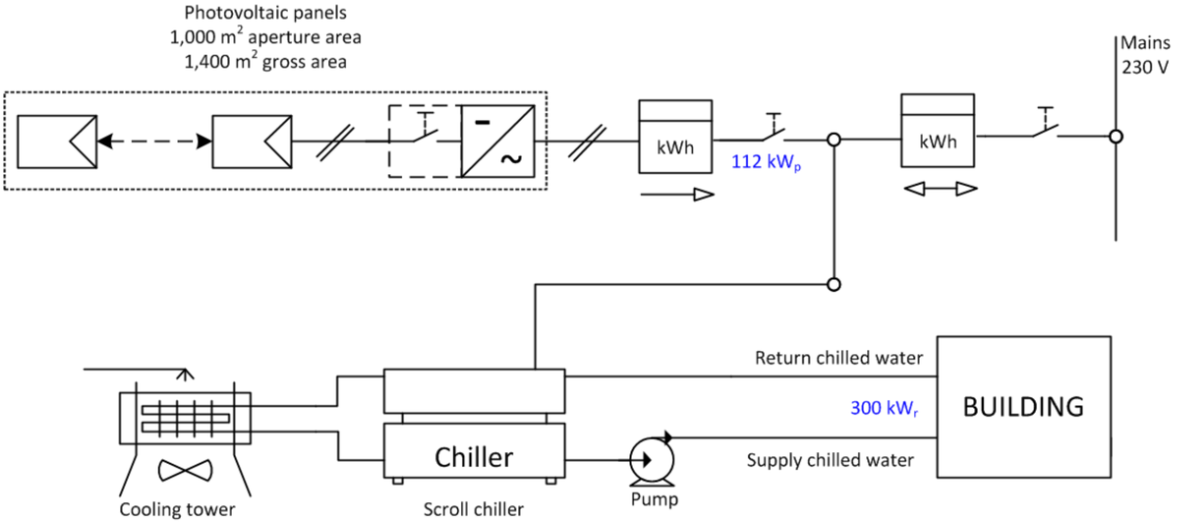

Fig. 2. System schematic of solar electric A/C system (PVAC)

The photovoltaic (PV) modules in the PVAC system have been assumed with an annual average efficiency of 14%. A degradation of the module efficiency of -15% over the 20 year lifetime has been assumed. The PVAC system yield has been calculated using a zone-based rating factor of 1.382 MWh/kWp/a for Sydney, including a 15% loss due to annual self-shading of the panels [4]. Excessive power generated by the PVAC system is accounted for as net export to the grid at grid electricity cost. The scroll chiller is water-cooled using a wet cooling tower and has an annual average COP of 2.5.

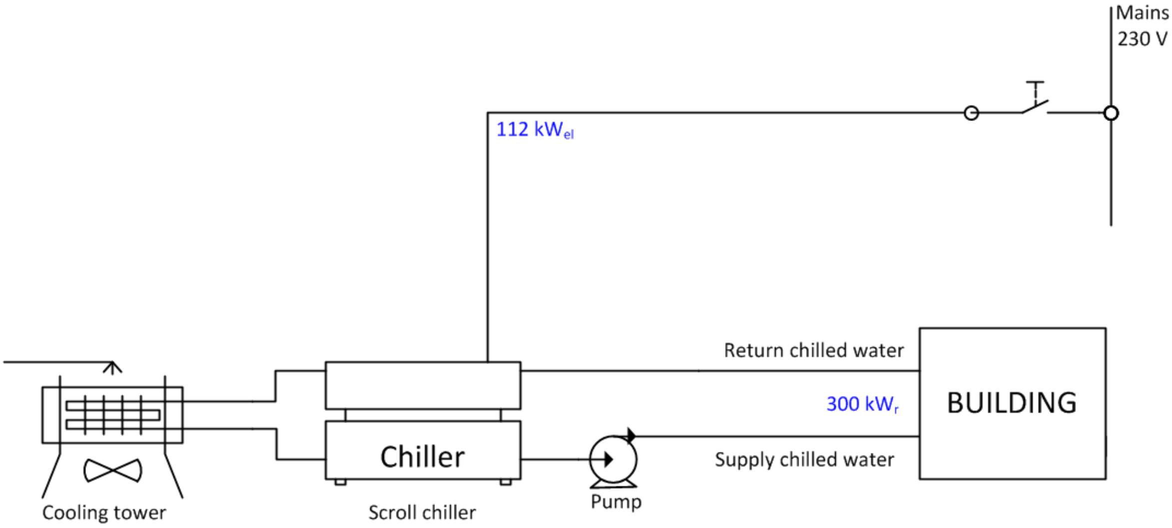

Fig. 3. System schematic of conventional A/C system (REF)

For the reference (REF) system the same chiller and cooling tower as for the PVAC system is assumed.

The comparison in this paper is made for a theoretical medium-sized commercial office building with a peak requirement of 300 kWr cooling capacity. The following general assumptions have been made:

- All three scenarios have been investigated for the climate zone of Sydney.
- The cooling demand is 293 MWhth per year in the building
- The heating demand is 21 MWhth per year in the building
- The hot water demand is 6 MWhth per year in the building
- No electrical storage is being used
- No subsidies have been assumed
- No feed-in tariff has been assumed for photovoltaic power generation
- All three systems have been designed to provide 100% of the annual cooling load (293 MWhth/yr) as well as to cover the peak cooling capacity (300 kWr)
- A gas boiler is assumed for the heating and hot water demand in scenarios PVAC and REF.
- No gas boiler is assumed for scenario STAC – the system is designed such that heating and hot water demand are covered by solar energy.

The comparison was made by modelling all three systems, calculating annual performance and energy yield. Further, investment and operation and maintenance (O&M) costs have been calculated and an economic analysis using net present cost (NPC) for a lifetime of 20 years has been conducted.

Table 1 shows the financial assumptions for the economic calculations. The system specifications are given in Table 2 and the costing in Table 3.

Table 1. Financial assumptions for NPC calculations

| Financial assumptions | All Scenarios |
|---|---|
| Lifetime of scroll chiller | 15 yrs |
| Lifetime of absorption chiller, collectors & PV modules | 25 yrs |
| CPI (inflation rate) | 2.5 % |
| Discount (interest) rate | 5.0 % |
| Electricity cost (industrial, incl. supply charge) | 0.23 $AU/kWhel |
| Annual escalation rate electricity cost | +5.0 %/a |
| Gas cost (industrial, incl. supply charge) | 25 $AU/GJ |
| Annual escalation rate gas cost | +3.0 %/a |

Table 2. System specifications for NPC calculations

| System parameter | STAC | PVAC | REF |
|---|---|---|---|
| Nominal installed cooling capacity (kWr) | 300 | 300 | 300 |
| Average annual COP of chiller (-) | 1.1 | 2.5 | 2.5 |
| Nominal installed thermal capacity (kWth) | 273 | - | - |
| Nominal electrical power required for A/C (kWel) | 11.5 | 120 | 120 |
| Net solar aperture area (m2) | 588 | 567 | - |

Table 3. Cost assumptions for NPC calculations

| Investment Cost | STAC | PVAC | REF |
|---|---|---|---|
| Collectors / PV Modules | $215,600 | $136,800 | $- |
| Chiller including recooling | $198,667 | $166,400 | $166,400 |
| Hydraulic / Electrical incl. Inverters | $153,200 | $106,800 | $27,533 |
| Gas boiler | $- | $60,000 | $60,000 |
| Planning and Installation | $95,096 | $134,138 | $62,598 |
| Total equipment cost | $662,563 | $604,138 | $316,531 |
| specific system cost ($AU/kWr) | $2,209 | $2,014 | $1,055 |
| specific system cost ($AU/m2 net solar aperture area) | $1,127 | $1,065 | - |
| specific system cost ($AU/m2 NLA) | $259 | $236 | $124 |
| Annual average O&M cost ($AU/a) | $11,247 | $11,002 | $51,515 |

The capital investment cost and the relative component costs within each system are represented in Figure 4 below:

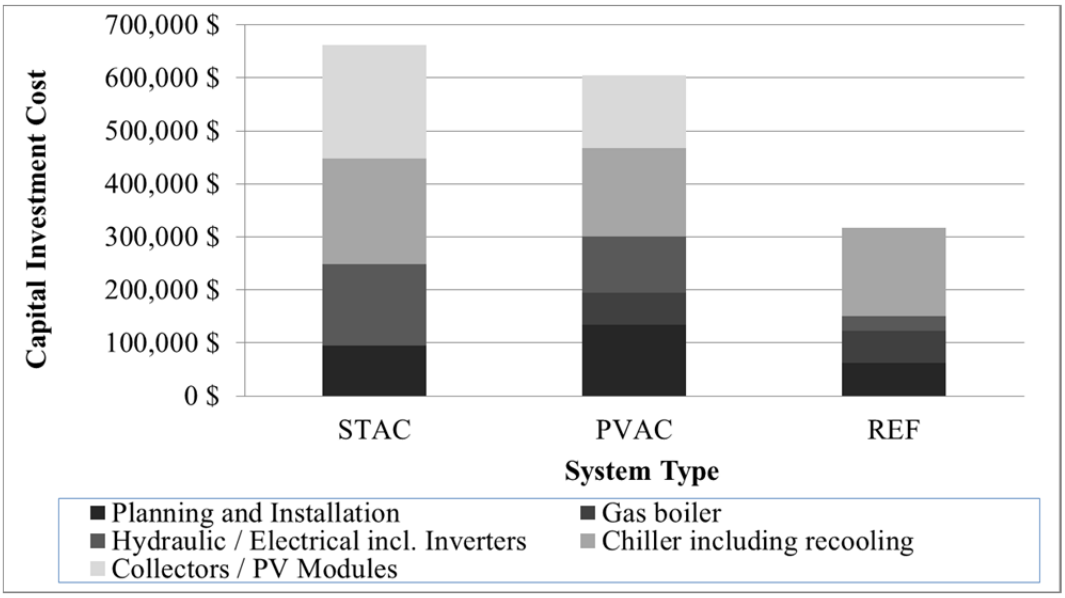

Fig. 4. Capital investment cost and component costs for each system

## 3. Results and discussion

As shown in Figure 5, the NPC (20 year lifetime) of the solar thermal cooling system ($792,144) was marginally less than that for the solar electric cooling system ($809,361). Both systems have an NPC more than 20% lower (refer Figure 6) than the reference grid connected air conditioning system ($1,018,343). The Levelised Cost of Cooling Energy (LCCE) is directly proportional to the NPC, represented as c/kWh_r, and is shown in Figure 5 below. LCCE is a useful metric for comparing alternate systems and sizes of systems.

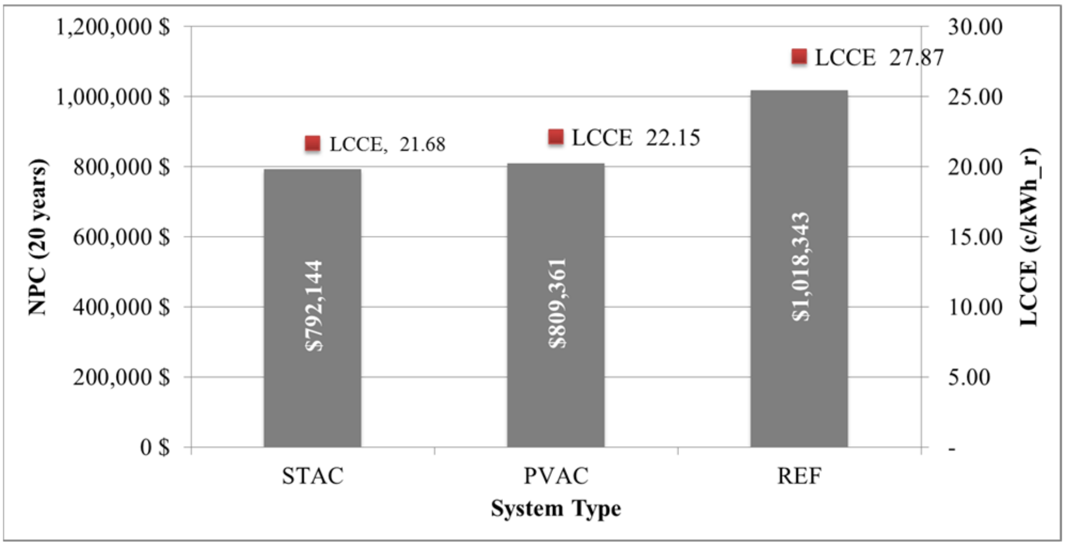

Fig. 5. Lifetime Cost based on 20 year operation

The NPC and LCCE results are in direct contrast with the upfront capital cost with the reference system approximately 50% of the capital cost of the other systems, refer Figure 4. While the financial return over the life of the system is evident for solar thermal cooling, the take up of solar thermal systems in Australia has been poor compared to Europe. We consider the reasons for this to be:

- Lack of understanding and awareness of the technology from developers and consultants
- Although the system components are available off the shelf internationally there is a lack of suppliers of key components in Australia, and a lack of businesses consolidating these components into viable operational systems.
- High capital cost is a barrier to entry of this technology into the market, where feasibility studies are based on capital cost not lifetime cost as landlords pass on operational costs to tenants.

These barriers do not exist for solar electric energy as it is a well understood and proven technology that has been commercially available for some time in Australia. However, it has commonly been considered as a token source of electricity to supplement a buildings energy usage to display a building owner’s environmental commitment; it has generally not been specifically sized to meet the energy requirements of a buildings air-conditioning system.

The analysis shows that through the lifecycle of the major building plant and equipment (20 years) the solar thermal and solar PV systems provide a significant financial benefit to building owners through reduced operational costs or outgoings. The benefits to tenants of commercial buildings with solar cooling systems installed are reduced outgoings (an additional rental component calculated annually by landlords and charged to tenants to cover the costs of building operations) and potentially reduced after-hours airconditioning costs. After-hours airconditioning costs are charged by landlords when a tenant seeks to have airconditioning turned on outside normal business hours, typically after 6pm or on weekends. The rates for after-hours airconditioning are high as normally require the buildings central plant to be fully operational while only servicing a fraction of the buildings floor area. Solar thermal systems have the advantage of being able to store the heat generated during the day to provide air-conditioning after-hours at minimal cost. This would be particularly beneficial to business that operate 24 hours / 7 days such as manufacturing or call centres. Solar electric systems would require battery storage to provide an equivalent improvement in after-hours air-conditioning.

A further advantage of the solar thermal and solar photovoltaic systems is the very significant reduction in greenhouse gas emissions from the energy required for air-conditioning. While there is 20% improvement in the lifetime cost of the solar cooling systems there is a 90% improvement in Greenhouse Gas Emissions.

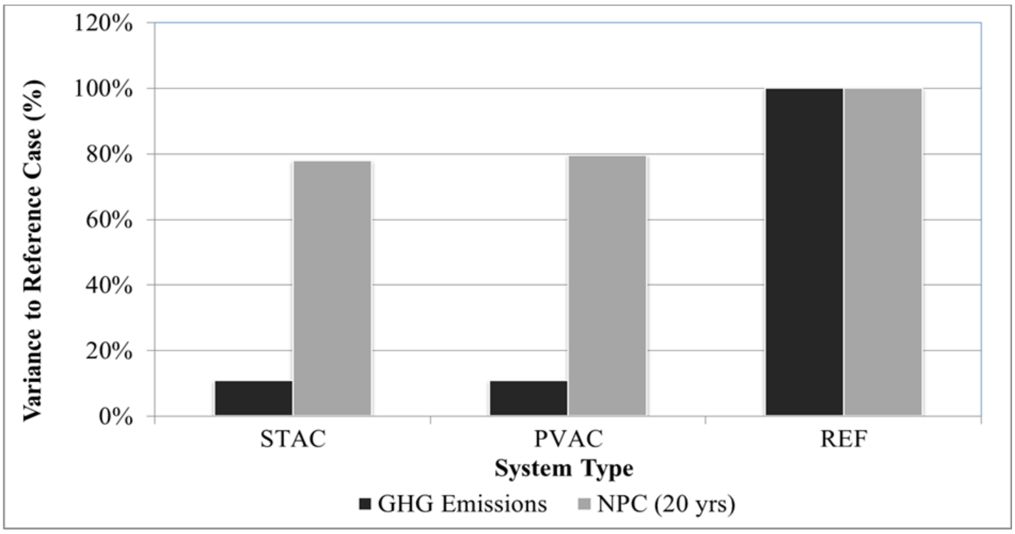

Fig. 6. Greenhouse Gas Emissions and Lifetime Costs Comparison

These improvements in lifetime cost and greenhouse gas emissions add value to the building as an asset for building owners by supporting the buildings environmental ratings, be they NABERS, Green Star or international ratings including LEED, and makes the building more attractive to prospective tenants through its environmental credentials and reduced operating costs.

There are multiple assumptions built into the financial model which will change over time. In order to test the robustness of our conclusions we modelled the results based on the following scenarios:

- Scenario 1 – escalation rate of electricity price varying
- Scenario 2 – effect of changes in built area
- Scenario 3 – changes in capital cost of key components of solar thermal and solar PV systems

In addition, the application of the conclusions to different climatic zones was tested by comparing the results for Sydney to Brisbane (Scenario 4).

### *3.1. Scenario 1 – Escalation Rate of Electricity Price*

Electricity prices escalated at a rate of 7% per annum during the period 2011 – 2015 in Australia [5]. Some claim this is due to the cost of upgrading aging infrastructure; but it is also noted that this period coincides with the privatisation of electricity generation and distribution. Electricity price escalation may continue or may be artificially stabilise by political pressure as has become a major issue for governments due to impacts on cost of living. The analysis assumed a 5% annual increase in electricity prices. This is well above CPI but consistent with recent history of electricity prices and forward predictions. Referring to Figure 7, lower percentage increases will reduce the difference between the lifetime cost of solar thermal and PV systems when compared to the reference system, although it is important to note that at a 1% annual increase, the solar thermal system remains the lowest lifetime cost. As the percentage annual increase exceeds 5% the lifetime cost of the reference system increases exponentially compared to the solar thermal and solar PV further improving the business case for these systems. Interestingly the difference between the solar thermal and solar PV systems narrows with the increasing electricity price; this is largely due to the added value of the unused energy generated from the solar PV system that is returned to the grid.

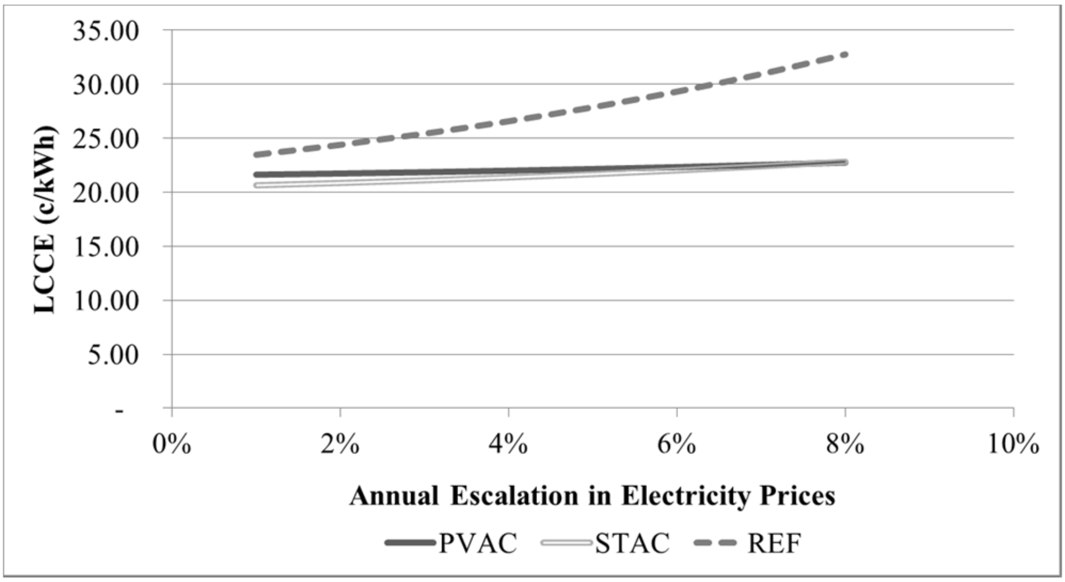

Fig. 7. Effect of Changes in Electricity Price Escalation

### *3.2. Scenario 2 – Effect of Changes in Built Area*

The building footprint is a constraint on the solar thermal and solar PV systems as these systems require a large roof area to generate sufficient thermal or electric energy. From Figure 8 – a reduced built form increases the LCCE while a larger built form reduces the LCCE. A marginal change in built form will typically not make significant changes to the major plant and equipment required for airconditioning and therefore the capital cost of the installation. This shows that system design needs to be optimised as far as possible within available systems and equipment capacities to minimise capital cost and maximise energy generation.

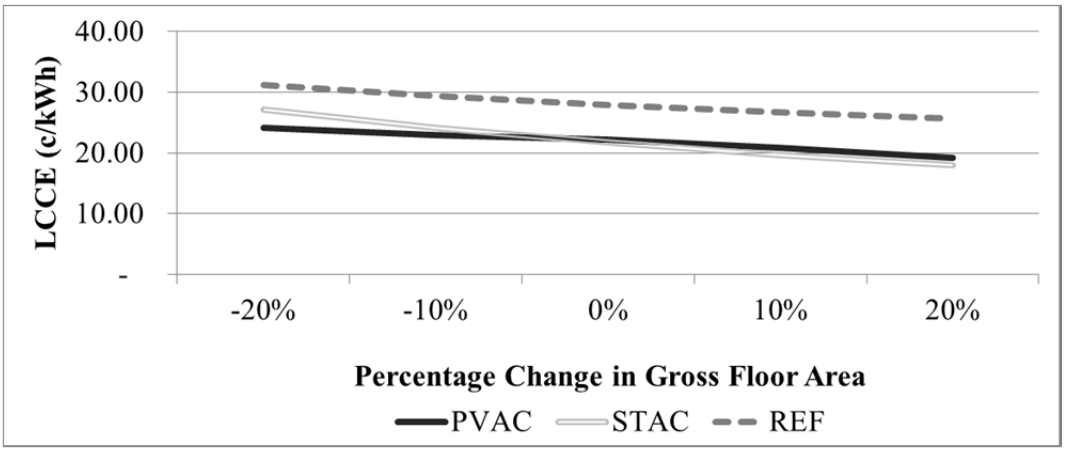

Fig. 8. Effect of Changes in Built Area

### *3.3. Scenario 3 – Changes in capital cost of solar thermal and solar PV plant and equipment*

Solar Thermal remains a developing technology when compared to solar PV and traditional grid connected systems. It is therefore expected that very significant drops in component costs will occur in the next few years, in a similar way to the very significant costs we have witnessed in the cost of solar PV cells. Referring to Figure 9 – a 20% reduction in the cost of solar thermal specific plant and equipment will reduce the LCCE of the solar thermal system to 20c/kWh, almost 8c/kWh or a 30% reduction in the lifetime cost of the reference system. A 30% cost reduction in the reference system is something that can no longer be ignored by the Australian commercial office markets.

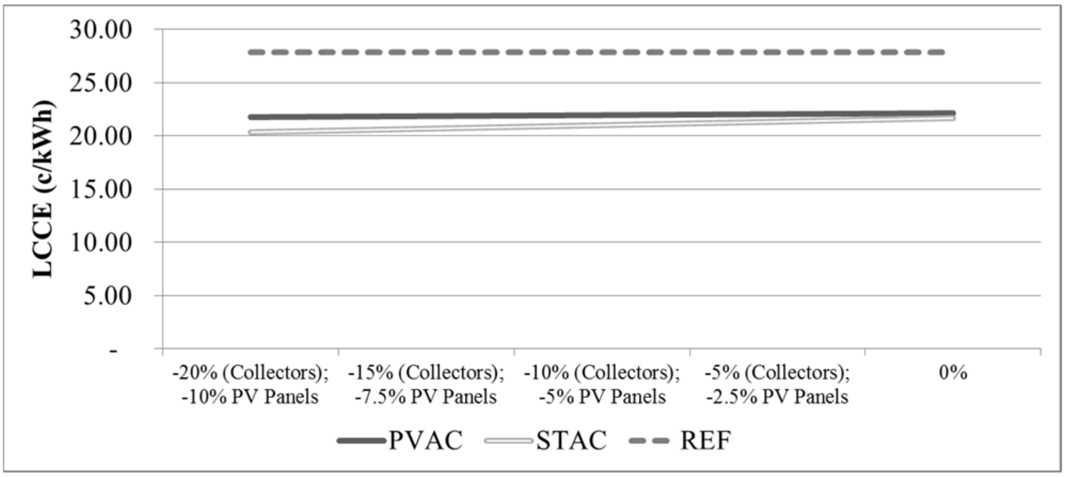

Fig. 9. Changes in LCCE due to changes in capital cost of solar thermal and solar PV plant and equipment

### 3.4. Scenario 4 – Comparison of Air-Conditioning System Installations in Sydney and Brisbane

The above calculations for NPC, over 20 year lifetime, were calculated for Brisbane and compared to the results for the three technologies in Sydney. Brisbane has a different climate to Sydney and a higher solar irradiance. For the PVAC system yield a rating factor of 1.536 MWh/kWp/a for Brisbane was used.

The fundamental difference in the results between Sydney and Brisbane, as demonstrated in Figure 10 is that the LCCE of the reference grid connected system is significantly higher due to the higher cost of electricity in this location and the higher demand for air-conditioning. The solar thermal and solar PV systems are not impacted by this cost increase and are therefore largely unaffected. We see a marginal increase in LCCE for Brisbane for both systems as a result of the higher demand for air-conditioning in this environment. Therefore, we can conclude that in regions of higher solar irradiance and higher temperatures with a greater demand for air-conditioning the lifetime or NPC cost advantages of solar cooling over a grid connected system are even more pronounced.

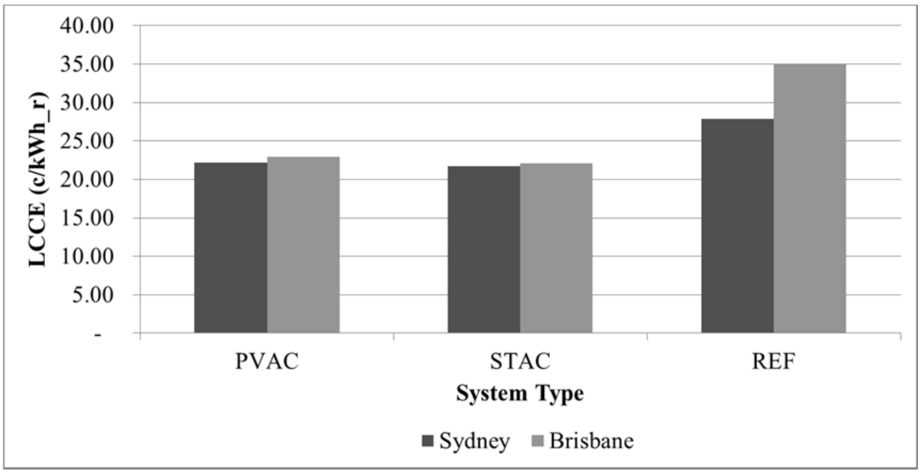

Fig. 10. Comparison of LCCE of Air-Conditioning System Installations in Sydney and Brisbane

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