City of Sydney trigen master plan

Energy Efficiency plus renewables can do it better

Submission from Beyond Zero Emissions
Suite 10, Level 1
288 Brunswick St
Fitzroy, Victoria 3065
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Summary

The city of Sydney is to be congratulated for seeking to address problems of energy efficiency, greenhouse emissions and electricity grid peak load congestion.

However, we find that the distributed energy network in the Trigeneration Master Plan (referred to as the trigen plan here) is the wrong solution for the problems identified.

In recent years, the energy efficiency attained by electric (heat-pump based) building chillers has risen to a level where trigeneration cannot compete for efficiency in any likely scenario. These systems are also cost-competitive with absorption chillers used in trigeneration.

Powering these electricity-driven systems with renewable energy is more feasible with the current electricity grid than attempting to provide large quantities of renewable biogas to operate less efficient trigeneration systems.

In the existing gas supply network, which is not supplied by biogas, the implementation of the trigen scheme will increase overall demand for gas. In current circumstances this will lead to increased production of highly polluting and unpopular coal-seam gas (CSG).

Our preferred option is energy efficiency plus renewable energy. This is backed up by our own research into 100% renewable energy grids and energy efficiency measures to drastically reduce the carbon footprint of buildings.

The 2010 Zero Carbon Australia Stationary Energy Plan and the soon-to-be-released Zero Carbon Australia Buildings Plan outline the measures by which we find that the electricity grid can go to 100% renewables based on wind and solar energy, and commercial office buildings such as are typical in the Sydney CBD can reduce their energy use by over 70%.

It only requires a partial implementation of our 100% renewable energy scenario to achieve the same emissions savings as envisaged in the trigeneration scheme.

This submission will outline key limitations of trigeneration technology. It will survey the technologies and approaches to achieving our preferred outcome.

We hope this brief treatment of the issues will convince the City of Sydney that further investment into the trigeneration plan is throwing good money after bad, and they would be better off looking to the latest building energy efficiency, HVAC (building chiller) and renewable energy technology for an efficient, cheap solution.

Trigeneration is inflexible and inefficient

Trigeneration uses absorption chillers which typically have a COP (co-efficient of performance) of around 0.7; ie, the cooling output is 70% of the input energy (heat).

Absorption chillers have to be optimised to the size of the expected waste heat stream. "For example, if absorption chillers with twice the COP were used this would have the effect of either reducing electricity generation by 50 per cent or rejecting 50per cent of the waste heat. Neither is desirable or efficient and would significantly reduce carbon abatement which is why the COP of absorption chillers have to be selected to fit the waste heat output," as Allan Jones explained in a RenewEconomy article. http://reneweconomy.com.au/2012/sydney-trigen-the-low-down-on-emissions-23079

As the waste heat stream goes up and down with electricity generation, then, the chillers must fit the normal heat output, to run at greatest efficiency. This makes the system very inflexible because the heat (hot water) output is sized to the electricity output of the gas-fired engines, not to the weather, or the cooling load at the time of generation.

For this reason, whilst an absorption chiller could be sized to meet the peak demand requirements of building airconditioning, it is more efficient (and common) to keep the pre-existing electric chiller available for the mid-afternoon peak requirements.

Existing electric powered building chillers typically installed would have a peak output COP of 2.5-3.0 in most cases, which is low by modern standards although still higher than that of an absorption chiller.

Absorption chiller purchase cost is not included in the Trigen Master Plan costings, putting the cost burden on building owners: "Thermal energy is priced such that it is cost–effective for customers to purchase and transform the generated heat into cooling, in comparison to standard cooling systems being powered by GreenPower. Thermal energy used directly for heating is also cost–effective in comparison to customers utilising and powering standard heating systems." (Master Plan, P.32)

In the case of one typical city building, we find that possible trigen systems at best represent a moderate increase in primary energy use as compared to the existing grid, and a moderate decrease in emissions. This case study is explained in the final section of this submission.

CSG and gas emissions

Building the trigen network will result in demand for extra gas in NSW. This is because it is displacing grid electricity that is largely drawn at present from non-gas sources (ie coal).

NSW gas supply is currently in doubt. As reported in the Sydney Morning Herald in April, the NSW state government has warned that "Bass Strait and Cooper Basin gas supplies are dwindling at a time when the gas export industry is growing at an extraordinary rate." http://www.smh.com.au/environment/energy-smart/gas-supply-to-dwindle-in-the-next-two-years-20120418-1x7pq.html

This means that, for the forseeable future, the demand for extra gas will stimulate growth in the dirty unconventional gas sector – shale gas in SA, and coal-seam gas in QLD and NSW.

This will reduce or even negate any hoped-for environmental benefits of the trigen plan. Coal-seam gas and shale gas have been linked to high rates of fugitive methane emissions in gasfields in the US and there are fears that the same problems may be occurring here.

Methane, i.e. “natural” (fossil or biofuel) gas, is a particularly potent greenhouse gas, with a global warming potential (GWP) of 21-25 times CO_2 over 100 years, and estimated to be over 100 at a shorter 20 year GWP.
(Shindell et al *Improved Attribution of Climate Forcing to Emissions*. Science 326, 716 (2009)).

This is in addition to localised pollution affecting groundwater, rivers and farms, and a generally high land use footprint, from unconventional gas development.

The Australian Energy Market Operator predict that 84-85 per cent of the nation’s future gas will come from unconventional (read coal seam or shale gas) fields. From an ecological point of view, this would be undesirable and finding renewable, non-polluting alternatives is important.

Given that the Trigeneration Master Plan has been developed with Origin Energy’s subsidiary Cogent, and Origin are a big name in CSG, a contract for gas supply with Origin can reasonably be seen as a contract to power the trigen plan on CSG for the forseeable future.

Rising gas prices

Gas prices are rising and likely to rise significantly further. Key factors are the decline in conventional gas supplies (already mentioned above) in the southeastern states.

The associated move into CSG and shale gas, and the increasing export market for LNG, are also pushing up the price of gas. This calls into question the economics of the trigen proposal.

Modeling of retail gas price increases done for BZE indicates that South Eastern states can expect a typical household gas bill to rise over 50% by 2020 and almost 100% by 2030. This is based largely on network and wholesale gas costs, which affect non-household users as well.

Gas supplier Santos has admitted that their move into shale gas will double wholesale costs. (http://www.adelaidenow.com.au/news/south-australia/secure-gas-will-come-at-a-higher-price-to-customers/story-e6frea83-1226452928723)

Dr Jenny Riesz of AECOM has pointed out that the increasing exports of LNG via the Gladstone LNG hub will also put pressure on prices, as domestic Australian prices are increasingly tied to international prices in the East Asia region – which are often several times the current Australian domestic gas price.
http://www.aecom.com/deployedfiles/Internet/Geographies/Australia-New%20Zealand/DeliveringEnergyPriceSecurity_DrJennyRiesz.pdf

Biogas is a limited resource

It has been suggested that the trigen scheme could be powered with renewable biogas. However, the 17PJ of gas that would be required annually would require a larger amount of biomass feedstock to convert to biogas, probably in the order of 25-30PJ primary energy.

CSIRO (Farine et al 2012) estimates of biomass availability include 240-280PJ/year of what BZE would consider sustainably harvested biomass. The likely requirements of the City of Sydney would take up more than 10% of this limited resource, when the conversion factor to biogas is considered.

This would be competing against not just electricity demand in other centres but all other possible uses, including transport and industrial feedstocks, and biochar production to draw excess carbon out of the atmosphere.

Chemical and industrial processes that rely on gas as a feedstock are considerable. *Australian Bureau of Agricultural and Resource Economics*'s figure for chemical processes in Australia is 115 PJ.

If we aim to clean up Sydney CBD buildings' emissions, it makes no sense to do so at the cost of our ability to clean up other sectors of the economy.

The trigen plan is an unreasonably large demand on a limited resource. Biogas, and biomass more generally, are very valuable but using them for electricity generation is a low-value option. Other sources of renewables such as solar and wind are well suited to this, and ready to be scaled up to supply a large proportion of demand (as is being done in South Australia for example, where wind farms supplied over 30% of that state’s energy in the first quarter of 2012).

Our modeling of comparison scenarios

Our energy flow diagram (see Figure 1 following this) was developed to contrast the energy use in the trigen plan with alternative scenarios for providing energy and energy efficiency to city buildings.

The following section explains this in more detail.

The original diagram in the Master Plan (page 9) was used as the basis for our own diagrams.

Our figures that Figure 1 is based on can be found in the spreadsheet accompanying this submission.

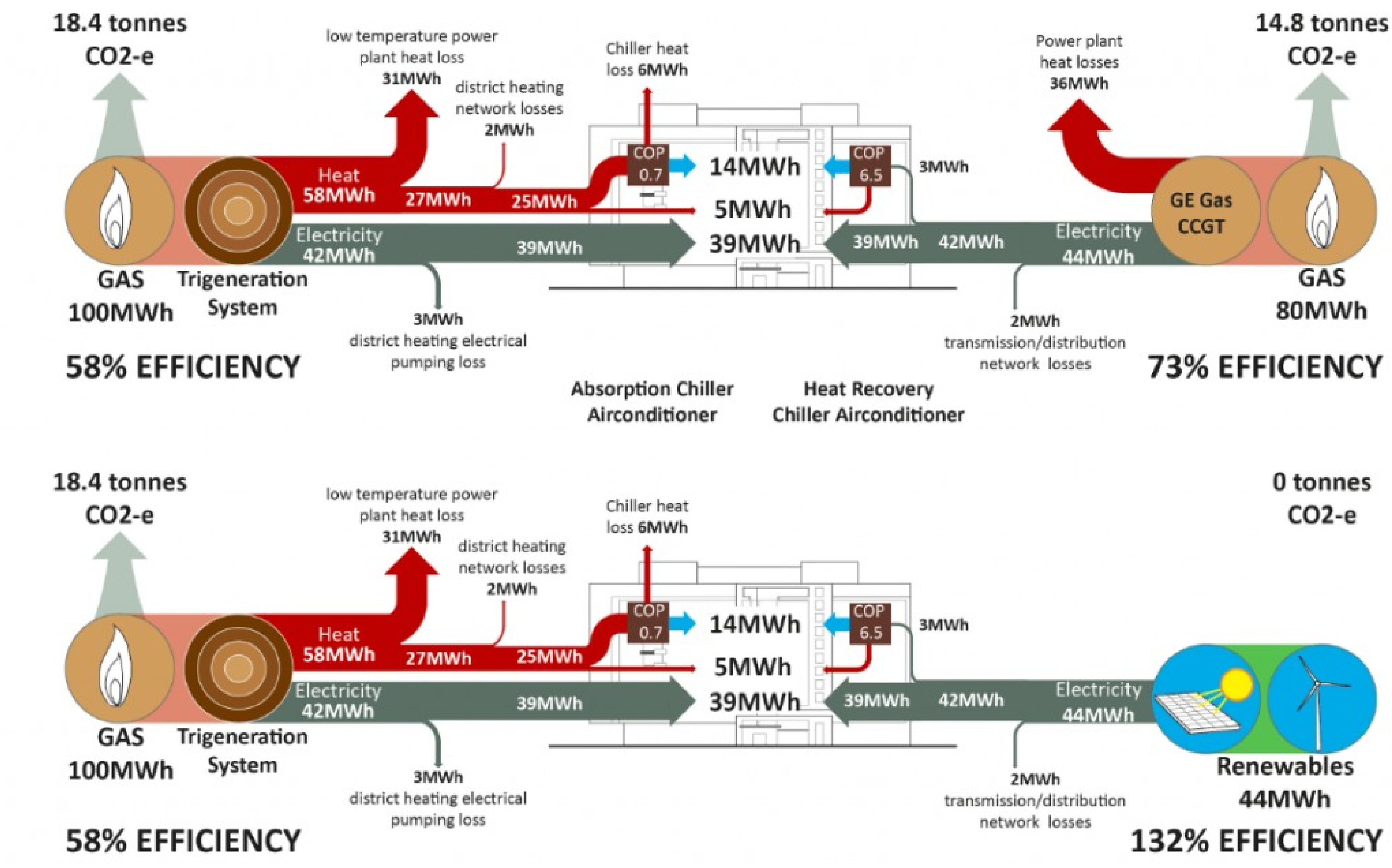


Figure 1: Comparison energy flow diagram

1. Energy flows in trigen plan

In the trigen plan, burning 100MWh of gas will provide 14MWh of cooling, 5MWh of heating and 39MWh of electricity. 100MWh of gas was the figure chosen in the Master Plan as an indicative figure to demonstrate percentage efficiencies. We have continued with their end use figures (14/5/39MWh) for our comparisons using alternative technologies that burn less gas (or require less input energy) for the same end use energy.

At each stage of the process, some energy from the original 100MWh gas is lost. The main loss is waste heat from the trigen engine that is not captured for use.

Further energy losses result from the electric pumps that circulate the district heating water, heat lost in the hot water distribution pipes, and heat loss from the inefficiency of the absorption chiller (which is expected to run at COP 0.7 which is fairly standard).

These losses were not clearly shown in the flow diagram in the Trigeneration master plan, mentioned above.

Our analysis reduces the overall efficiency claimed by the City of Sydney scheme: of the original 100MWh gas in their sample scenario, 58MWh actually reach the building as useable energy. This is down from the 67MWh implied in their diagram, which did not show the 6MWh (heat) lost by the absorption chiller and the 3MWh (electrical) used to pump the hot water in their district heating network.

2. CCGT plus upgraded chillers

BZE does not support the building of new gas generation plant to supply electricity, either centralised CCGT or decentralised trigen.

However, if such new gas generation plant were to be built, our figures indicate that a dedicated CCGT plant feeding into the electricity grid, coupled with energy efficiency (including the upgrade to modern heat pump based chillers), would result in higher energy efficiency and lower emissions than the proposed trigen master plan.

This scenario also assumes that instead of purchasing a heat-driven absorption chiller with a COP typically around 0.7, city building owners will upgrade to the latest electric chillers (available at a price that is competitive with that of the same capacity absorption chiller). New electric chiller systems, based on heat pump vapour compression technology, typically achieve a COP of 6.5 at peak cooling output.

At normal output their COP is even higher, as shown in the Master Plan (technical appendix, page 7). For example, a PowerPax 1400kW water cooled chiller has an Integrated Part Load Value of COP 10.72.
http://www.powerpax.com.au/products/id/15/cid/10/parent/0/pid/1/t/products/title/1400kWr+Water+Cooled+Chiller+%28Horizontal%29

For the purposes of our modeling we have conservatively used a peak output COP of 6.5, although this would probably be a lot higher in practice, as peak output only occurs a small part of the time.

As mentioned above, this is more than a doubling of efficiency from the chillers installed currently in many buildings which are commonly in the region of COP 2.5-3.0.

Not shown in this flow diagram is the fact that the remote CCGT option does not require new construction/upgrade of existing energy networks (hot water distribution pipes and gas mains): it relies on the existing electricity grid.

While peak electricity use is driving costs up on the electricity grid, our chiller upgrade alone would see peak electricity demand drop significantly.

The noticeably greater efficiency in this scenario (only 80% of the amount of gas needed for trigen) is largely from the high efficiency of the modern chillers: 3MWh of electricity supplies 19MWh of heating and cooling.

This would represent a significant reduction in emissions, based on using dedicated CCGT gas plant (which in high-efficiency modern models can reach 55% and theoretically higher); and due to upgrading existing chillers from older models to highly efficient modern ones.

3. Energy flows with 100% renewable energy

If 100% renewable energy were commissioned to supply the energy needs of the City buildings of the trigen scheme, we would need much less primary energy.

This is because renewable wind and solar do not lose part of the primary energy as waste heat. Wind and solar energy is harnessed or not, without waste either way. The Primary Energy Ratio for fossil fuels (and renewable biogas) is used to recognise the energy wasted (primarily as heat) from transforming the chemical energy stored in the original fuel into electricity.

In the 100% renewable energy scenario, therefore, the only significant energy loss is transmission losses from getting the energy to the city from more or less remote locations.

Due to the high COP of the upgraded chillers, the amount of renewable energy harnessed as electricity would in fact be less than the amount of end-use energy provided, giving a theoretical 132% efficiency overall.

The city could commission a dedicated 330MW wind farm in the region (with as few as 44 Enercon E126 Wind Turbines rated at 7.5MWe each) to source the same as half of the annual electricity supply forecast under the tri-gen plan; and 660MW of photovoltaic solar panels for the other half.

This would produce 1042GWh production from each annually, assuming 35% capacity factor for wind, and 18% capacity factor for solar PV.

The solar panels could be installed in the City of Sydney and two or three of the neighbouring municipalities with just 130,000 5kW rooftop systems (Australia currently has over 700,000 rooftop solar systems on private residences alone).

4. Amount of renewables for emissions savings equivalent to trigen plan

In order to match the trigen plan's projected emissions reductions, based on current grid emissions intensity, less than 100% renewable energy would be required.

In order to achieve the same amount of emissions total as the trigen scenario, BZE calculated that 39% of the city's energy would need to come from new renewable energy sources, while the remaining 61% could come be supplied from the existing grid which is primarily supplied with dirty black coal power.

In the short term, partial implementation of the solar and wind energy developments suggested above could be achieved at a cost comparable to that of implementing the trigen plan.

This would be doubly useful, because going to 39% renewable energy from wind and solar does not preclude going the rest of the way to 100% renewables at a later date.

Greater emissions reductions would be much harder to achieve with the trigen plan due to the limited supply of sustainable biomass and the poor energy efficiency constraints.

BZE's approach: Energy Efficiency Plus Renewable Energy

The only energy efficiency measure considered as a direct comparison to trigen in our three scenarios above is a modern electric building chiller upgrade. A range of other energy efficiency measures could be implemented in either scenario, as outlined in our building case study above.

Energy efficiency plus renewable energy enable cost savings and emission savings with a high level of efficiency and flexibility, and the ability to keep going beyond short term targets to a future fossil-fuel-free energy system.

The approach will be iterated in more detail in the forthcoming Zero Carbon Australia Buildings Report. In the meantime, BZE hope our recommendations will be given favourable consideration and are happy to discuss them further with the City if need be.

A comparison modeling of BZE's approach in relation to an example city building, in comparison with trigen, follows.

Case study: Trigeneration emissions and comparative energy analysis for example office building

BZE has extensive data and information about electricity; space conditioning thermal energy; and domestic hot water energy, consumption in commercial buildings, from the soon to be released Zero Carbon Australia Buildings Plan.

This analysis has included a segmentation of the office stock into different typologies based on energy performance characteristics (for example type of walls, nature of HVAC system) with representative models being developed for analysis of possible energy reductions from retrofits. Thermal simulations were undertaken on these office models by WSP Built Ecology as “in kind” support for the ZCA Buildings Plan.

BZE has chosen to illustrate the differences in primary energy and emissions of the City of Sydney Trigeneration plan compared to several alternative measures using one of these base case office models. This office is constructed between 1980 and 2000 with curtain wall façade,water cooled chillers, central air handling unit with constant air volume and a single gas boiler providing space heating hot water.

The Zero Carbon Australia Buildings Plan will be the first comprehensive nationwide retrofit plan for Australia's building sector.

Implementing this plan would halve residential energy use and lead to a 70% or greater reduction in non-residential building energy consumption.

Extensive research, modelling, and analysis has led to the selection of a suite of technologies and strategies aimed at decarbonising the existing building stock. These include:

1. Replacing all gas fired appliances/services with efficient electric alternatives, namely heat pump hot water systems, reverse cycle air-conditioners, and induction cooktops;
2. Fully insulating building envelopes – ceilings, walls, and floors – plus replacement double glazed windows and internal curtains with pelmets (in temperate climates only);
3. Reducing solar heat gain through windows with low-emissivity coatings and films, as well as added shading using external awnings (where possible and climate appropriate);
4. Full draught proofing;
5. LED lighting replacement for all lighting types;
6. Raising the bar on energy performance for electrical appliances to meet the best available today;
7. In house facility managers with training in energy efficiency and working to meet performance benchmarks;
8. Real time feedback via Energy Management Systems (commercial) and In Home Displays (residential) providing simple-to-understand energy figures benchmarked against expected demand and others in the local areas (e.g. neighbours);

9. On site renewable energy generation with solar photovoltaic and microwind.

These measures in combination are shown to achieve a 70% or greater reduction in building energy consumption from the modelling. Once factoring in the total building stock the research indicates that a nationwide 50% reduction in building energy consumption is viable.

These results are presented in this report for the building case outlined above.

Modelling has also shown that Australia has 30 gigawatts of rooftop solar PV capacity, which would lead to many buildings achieving the status of net generators – net exporters of electricity on an annual basis.

Over 80 active volunteers – engineers, architects, scientists, data analysts, and others – contributed to the project. Major engineering and design consultancies including GHD, WSP Built Ecology, Team Catalyst, VIPAC, Solem Consulting, Entura, as well as the Facilities Management Association, and a range of companies provided building size, type, and energy data.

Results

The primary energy consumption and greenhouse emissions from the example case office building in Sydney were considered for the following retrofit scenarios:

1. Remote Combined Cycle Turbine – with and without replacement vapour compression chiller
2. 100% Renewables – with and without replacement vapour compression chiller
3. 50% Renewables – with and without replacement vapour compression chiller
4. Trigen at precinct level (City of Sydney Plan) – Single effect and double effect absorption chiller
5. Full building energy efficiency retrofit as proposed in the ZCA Buildings Plan
    - LED lighting replacement
    - Fabric upgrades – insulation and low-e window film
    - HVAC upgrades – replacement chiller, heat pump space heating boiler, Variable air volume air handling, Variable speed drives on pumps and fans, economy cycle
    - Equipment and domestic hot water – laptop replacement and heat pump hot water

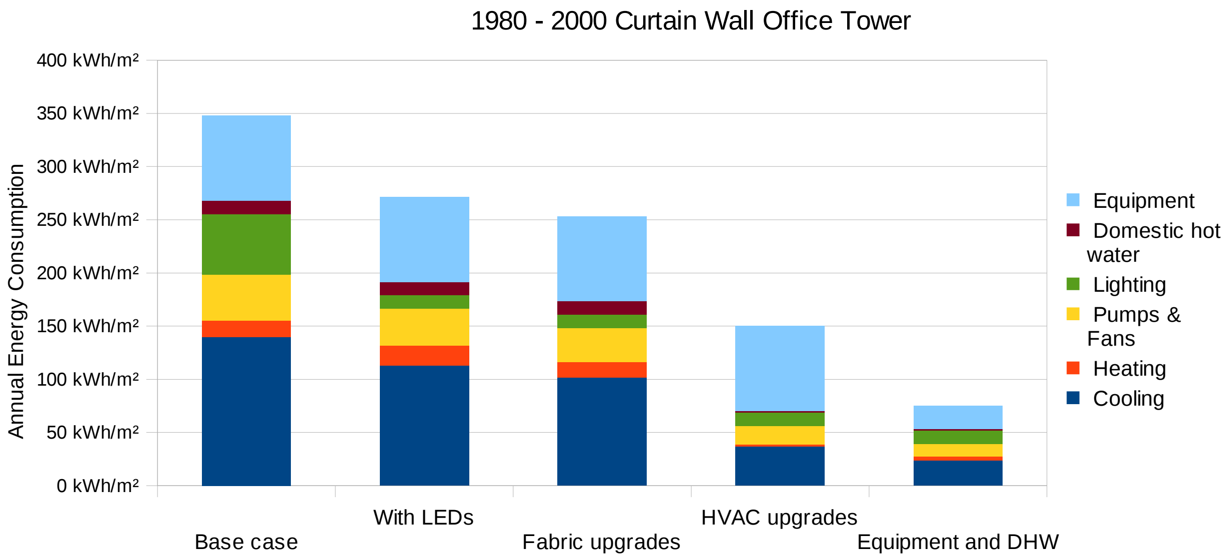
The results given in Table 1 below show that whilst primary energy and emissions savings are possible, they generally lower than all other strategies. The typical case and best case trigeneration precinct cases, with single effect absorption chillers, actually increases the amount of energy consumed by the building (as denoted by the negative percentages), therefore providing no energy efficiency benefit at all. The double effect absorption chiller cases do obtain real energy reductions on the base case, however only in the same range as that of the new vapour compression chiller retrofit.

From an emissions point of view the City of Sydney Trigeneration plan – represented by Case 4b, generates a reduction of 61% at best, but only a decrease in emissions of 34% with a single effect absorption chiller. This compares to 60% and 63% emissions reductions for the 50% renewable energy case with replacement vapour compression chillers. This is due to the substantial increase in input energy demand for the absorption chillers when compared to even the existing chillers.

This analysis illustrates the problems of purely considering the emissions reduction benefits from the point of view of a reciprocating gas engine. When factoring in the tenfold increase in chiller energy, due to the different Coefficient of Performance the picture is not as beneficial. The far better scenarios are those which involve a lower emissions energy supply coupled with energy efficiency measures, particularly upgrading old vapour compression chillers.

In contrast the ZCA Buildings Plan proposals for this building lead to a 78% reduction in final energy use as illustrated in Figure 1 below. The primary energy and emissions reductions on the base case scenario are given in Table 2.

Figure 1: Energy Reductions from ZCA Buildings Plan retrofits.



Primary Energy								
LEGEND			**No upgrade**	**% change**	**Chiller upgrade typical**	**% change**	**Chiller upgrade best**	**% change**
Case 1	BASE CASE		25068.1	NA	19908.2	20.58%	18764.7	25.15%
Case 2a	CCGT	Typical	16142.6	35.61%	12859.0	48.70%	12131.3	51.61%
Case 2b	CCGT	Best	14840.9	40.80%	11831.0	52.80%	11163.9	55.47%
Case 3	100% Renewables		9113.7	63.64%	7307.7	70.85%	7049.7	71.88%
CAse 3b	50% Renewables		17090.9	31.82%	13608.0	45.72%	13110.4	47.70%
					ABS Chiller upgrade typical	**% change**	**ABS Chiller Upgrade Best**	**% change**
Case 4a	Trigen Precinct	Typical			34698.7	-38.42%	20458.7	18.39%
Case 4b	Trigen Precinct	Best			28369.8	-13.17%	16766.9	33.11%

Emissions								
LEGEND			**No upgrade**	**% change**	**Chiller upgrade typical**	**% change**	**Chiller upgrade best**	**% change**
Case 1	BASE CASE		7959.6	NA	6321.3	20.58%	5958.2	25.15%
Case 2a	CCGT	Typical	2975.4	62.62%	2370.2	70.22%	2236.0	71.91%
Case 2b	CCGT	Best	2735.5	65.63%	2180.7	72.60%	2057.7	74.15%
Case 3	100% Renewables		0.0	100.00%	0.0	100.00%	0.0	100.00%
CAse 3b	50% Renewables		3979.8	50.00%	3160.6	60.29%	2979.1	62.57%
					ABS Chiller upgrade typical	**% change**	**ABS Chiller Upgrade Best**	**% change**
Case 4a	Trigen Precinct	Typical			6395.7	19.65%	3771.0	52.62%
Case 4b	Trigen Precinct	Best			5229.1	34.30%	3090.5	61.17%

Table 1: Results from primary energy and emissions analysis. Note units in top table are in kWh and units in bottom table are in kg CO2e and are daily averages

			Energy	**% change**	**Emissions**	**% change**
Case 1	BASE CASE		25068.1	NA	7959.6	NA
Case 1'	Post Retrofit		5383.3	78.53%	1709.3	93.18%
Case 2a'	CCGT	Typical	3469.4	86.16%	639.5	97.45%
Case 2b'	CCGT	Best	3190.3	87.27%	588.0	97.65%
Case 3'	100% Renewables		1962.2	92.17%	0.0	100.00%
Case 3b'	50% Renewables		3638.8	85.48%	577.7	97.70%

Table 2: ZCA Buildings Plan Efficiency Measures

Energy performance characteristics

Beyond Zero Emissions undertook desktop research and spoke with building energy experts to determine typical and best case performance characteristics for all the proposed abatement strategies.

	Case	COP	Eff(e)	Eff(t)	Emissions factor (kg CO2e/GJ)	Elec Parasites	Therm Parasites
Absorption Chiller	Typical	0.7				0.21%	
	Best	1.2				0.63%	
Precinct Gas Plant	Typical		42%	22%	51.2	3.00%	2.00%
	Best		44%	27%	51.2	3.00%	2.00%
Vapour Compression Chiller	Typical	6					
	Best	7					
CCGT	Typical		55%		51.2	5.00%	

	Best		60%		51.2	5.00%	
Base Case – NSW Ave Emissions Factor			35%		88.2	5.00%	

Table 3: Performance Characteristics of Energy supply and demand reduction strategies

The sources used for gas engines for trigeneration was GE[1] and MWM[2] and the City of Sydney Trigeneration Master Plan[3]. The sources used for absorption chilling was BROAD[4] and Thermax[5] and in communication with Solem Consulting. Vapour compression coefficients of performance (COP) where taken from energyrating.gov.au, Powerpax website[6], and are in line with the values contained in the Draft Zero Carbon Australia Buildings Plan. Efficiencies and emissions factors for CCGT plants and existing NSW black coal power stations were derived from the "Supply Inputs – Scenario 1 – 11 Jan 2011" spreadsheets from AEMO published as part of the National Transmission Network Development Plan and the "National Greenhouse Accounts Factors" 2011.

A schematic of an absorption chiller is shown in Figure 2. Like vapour compression chillers they pump a refrigerant around to different heat exchangers to draw in heat and reject heat. However they use water at low pressure as the refrigerant, which is vapourised when in contact with the cooling water in the evaporator. This vapour is absorbed by Lithium Bromide – a salt – and removed from the process, thereby removing heat. The salt absorbent needs to be reconstituted by a heating, which in the case of trigeneration comes from a gas engine. Electrical energy is required in this process (denoted as electrical parasites). The absorption chiller illustrated here is a single effect machine, however double and triple effect machines exist that include additional cycles to increase efficiency. Double and triple effect machines can achieve COPs in the range of 1.4 to 1.7, however values of 1.2 are common.

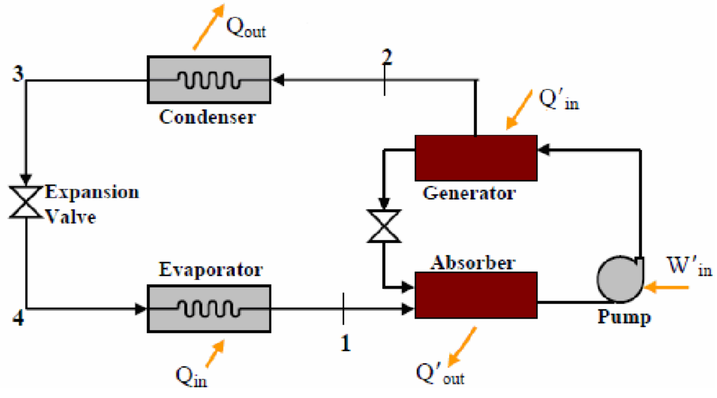


Figure 2: Absorption Chiller Schematic

This method is substantially less efficient than a traditional vapour compression cycle which uses a refrigerant gas, usually R134a but sometimes CO2. For water cooled

1 http://site.ge-energy.com/prod_serv/products/tech_docs/en/downloads/GER3430G.pdf
2 http://www.mwm.net/en/products/gas-engines-power-generators/tcg-2020-tcg-2020-k/
3 http://www.cityofsydney.nsw.gov.au/council/OnExhibition/documents/CityofSydney-DEMPTrigeneration-Report20101129-LowRes.pdf
4 http://www.broad.com:8089/english/product/zykt/x_normal.pdf
5 Thermax Cooling and Heating Division Hot Water Driven Absorption Machines, 2006
6 http://www.powerpax.com.au

(where heat is rejected to water that is evaporated through a cooling tower) vapour compression chillers for use in large office buildings, COPs of 6-7 are now common. This means that a single unit of electrical energy used to drive a compressor can extract 6 units of thermal energy from the ambient air. Substantial improvements in compressor design in the last 5 to 10 years to achieve these COPs mean that most HVAC systems operate with chillers performing at half this efficiency or lower (COP 3). The replacement of chillers is seen by BZE as a large opportunity for energy savings.

Whilst most gas engines used for trigeneration suggest thermal efficiencies of 45% and therefore overall efficiencies approaching 90%, this assumes that all recovered heat energy can be used in the absorption chilling process (or as another useful heat input into the building).

Heat recovery from the engine jacket and oil is usually exchanged with water to provide high temperature water ~ 90 degs. However it is possible to add an additional heat exchanger to the system that uses the engine exhaust to boost heat output to high pressure steam ~ 0.8 MPa. A typical single effect absorption chiller might operate off 90 deg hot water, whereas a double effect absorption chiller can use high pressure steam.

This has implications for the precinct level trigeneration, as it is safer and more economical to pump high temperature hot water around to buildings rather than steam. Whilst an increased flow rate on the heat exchanger could be possible, the trigeneration plants are sized for electrical output and this approach will produce a significant volume of hot water for which there possibly insufficient demand for in the Sydney CBD. This explains the low thermal efficiency quoted for the City of Sydney Master Plan – 27%.

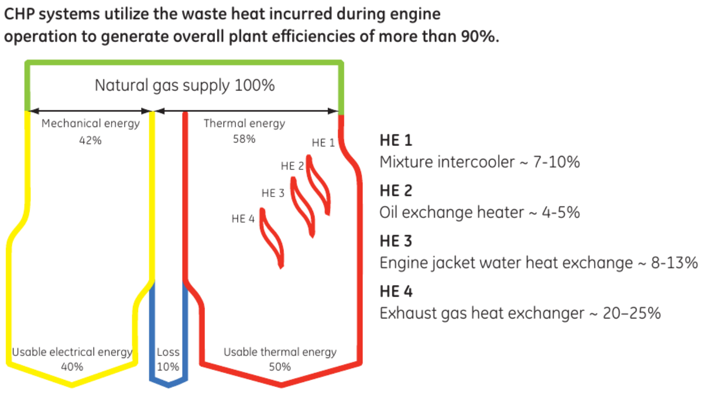


Figure 3: Sankey Diagram of energy flows in a GE reciprocating gas engine. Source: http://site.ge-energy.com/prod_serv/products/tech_docs/en/downloads/GER3430G.pdf

The precinct trigeneration system involves parasitic energy losses in the pumping of heat. This includes both thermal losses and the electricity required to pump. These have been factored in.

Finally the distribution loss factors for NSW where estimated using AEMO data[7] at 5%.

7 Distribution Loss Factors For The 2012 / 2013 Financial Year, AEMO, 2012

Base Case Building Data

The parameters of the building are contained in the table below:

Building Parameter		Base
Infiltration (perimeter zones)		1 ACH
Building fabric	**Walls**	Curtain wall
	Floor	Slab
	Roof	Concrete parapet
Bulk insulation (R-value)	**Walls**	N/A
	Roof	None
External Glazing	**Type**	Single glazed
	U-value	5.6 W/m²K
	SHGC	0.6
Shading	**Internal**	None
	External	None
HVAC Description		Gas boiler, central ducted AC
Chiller COP		3
Boiler efficiency		75% (gas)
Lighting		12 W/m²
Equipment		11 W/m²

Other assumptions:		Value
Number of storeys		10
Occupancy/density		15m² per person
Floor area		9000
Length: width ratio		1:1
Occupant heat load	**Sensible**	70 W/person
	Latent	60 W/person
Ventilation (L/s per person)		7.5
Floor to ceiling height (m)		2.7
Floor to floor height (m)		3.7
Glazing extent		73.00%

This building has been modelled using IES VE, a thermal performance simulation tool. This gives the results for average and seasonal peak energy consumption contained in the table below. The total annual average daily consumption is 347.7 kWh/m² or 1251.8 MJ/m². This compares well with the result from a similar building with 2.5 stars and similar equipment load using the NABERS Reverse Calculator[8] ~ 1400 MJ/m2. It should be noted this is a fairly inefficient building designed to represent the average of the existing stock and the resulting energy values are very high compared to best practice new buildings today (or even BCA 2010 compliant buildings).

Outputs	TOTAL PER ANNUM	TOTAL PER DAY	Summer Daily Ave	Winter Daily Ave

8 http://www.nabers.com.au/page.aspx?cid=630&site=2

Cooling	139.5 kWh/m²	3439.9 kWh	5409.8 kWh	1059.0 kWh
Heating	15.9 kWh/m²	392.1 kWh	301.8 kWh	616.8 kWh
Pumps & Fans	42.9 kWh/m²	1058.7 kWh	1649.2 kWh	344.7 kWh
Lighting	57.0 kWh/m²	1404.4 kWh	1380.6 kWh	1418.7 kWh
Domestic hot water	12.5 kWh/m²	307.6 kWh	301.7 kWh	311.1 kWh
Equipment	79.9 kWh/m²	1971.2 kWh	1944.2 kWh	1987.4 kWh

IES VE sizes the cooling plant required for this building to $2500kW_{th}$ (peak) coolth output. Based on a 15 hour operating time the summer daily average is $1000kW_{th}$. Whilst an absorption chiller could be sized to meet the peak demand of the HVAC system, the City of Sydney Master Plan proposes to keep the existing chiller for supplementary cooling. This is not ideal as the existing chiller is likely to perform poorly under peak load and acts as an inefficient redundant plant.

As a consequence the absorption chiller replacement size is 1000kW. The replacement vapour compression chiller has been sized at 2000kW to replace the entire capacity of the existing chiller.

An assumption has been made that the absorption chiller will supply half the annual/daily average of chilling demand. The remaining cooling being undertaken by the old vapour compression chiller. This is necessary because the cooling energy consumption is quite high and if the trigeneration system was sized to meet the full demand, with the low heat recovery efficiencies quoted, it would require a substantial primary energy – in the order of 70,000 kWh. Alternatively the trigeneration system could be solely sized on the electrical loads, which along with the high electrical efficiency quoted (42-44%) would only make available a small amount of hot water for the absorption chillers. The coolth output from the absorption chillers in this scenario would only amount to ~20% of the total cooling demand of the building.