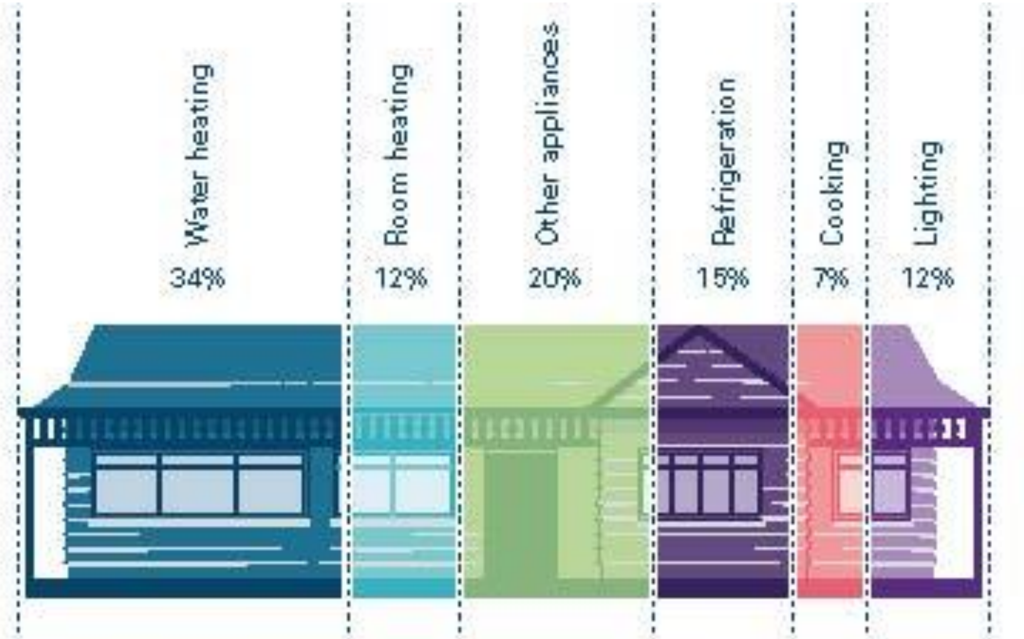
Introduction

The basis for our answer to this problem is based on finding our current electricity generation capacity and the rate at which our current electricity is increasing. We then researched statistics on the division of residential power consumption between main areas in the home. Based on this we identified areas where savings could potentially be made. This involves:

1. Retrofitting under-insulated homes with double glazing and ceiling and floor insulation. This maximises room heating efficiency. This is 12% of residential power consumption.
2. Efficient Lighting. We believe that application of fluorescent lighting in all homes is a reasonable demand as an energy saving measure. This could be introduced by compulsion.
3. Water Heating is a massive 34% of household energy consumption thus any increase in efficiency in this area will have a significant effect on power use.
4. Habitual saving. The New Zealand public has demonstrated before that in times of necessity, such as imminent brown outs, they are prepared to save 8%[1] of their power consumption and thus we have factored this into our possible maximum savings.



[2]

[1] www.tvnz.co.nz/view/page/411365/1846647
One News, 2003 power saving
[2] www.meridianenergy.co.nz/YourHome/Energy+and+cost+savings/At+home Meridian Energy

Our 4 part Energy Saving Scheme

1 Insulation

The energy required to heat a home is equal to the energy lost through the ceiling, walls, floor and windows. Changes to the building code that have resulted in improved insulation in new houses

The average new house has a floor area of 192m^2

Taking an average proportion of 3:2 length to width of a rectangular house and 3m wall height this gives us an overall wall area of 169.70m^2. The average house has 25% of wall area as windows and 75% as actual walls. This gives wall area of 127.28m^2 and window area of 42.425m^2. We have assumed that floor area is equal to roof area. We have calculated the rate of heat loss through these various surfaces of the house using Newtons law of Cooling. $\frac{dQ}{dt} = h\,.A\,(T_{outside} - T_{inside})$

Where $h = \frac{\Delta Q}{A.\Delta T \Delta t}$, A = Area of heat transfer surface. We have assumed that the average outside temperature in New Zealand is 10°C and the average inside temperature is 18°C. The building code has recently changed to require more insulation. We have used the building code for Zone 3 which is the most stringent, this area contains the South Island and the Central Volcanic Plateau.

The insulation properties of various surfaces are measured in R values. $R = \frac{\Delta T}{\Delta Q}$.

www.cleanenergyguide.org.nz says that a fully insulated home can almost halve the heating requirements. From this we have estimated that the R value of an uninsulated home is 0.6 of the R value of a fully insulated home (most stringent standard)

Roof

Uninsulated House	Building Code minimum prior to 31/10/07	Building Code minimum after to 31/10/07
R=1.98	R=2.5	R=3.3
h=0.002630	h=0.002083	h=0.001578
dQ/dt =-4.040	dQ/dt = -3.199 Js^{-1}	dQ/dt = -2.4238 Js^{-1}
Energy Loss per Year 35.39	Energy Loss per Year 28.02 kWh	Energy Loss per Year 21.23 kWh

Wall

Uninsulated House	Building Code minimum prior to 31/10/07	Building Code minimum after to 31/10/07
R=1.2	R=1.9	R=2.0
h=0.006547	h=0.004135	h=0.003928
dQ/dt =-10.045	dQ/dt = -4.1204 Js^{-1}	dQ/dt = -3.9996 Js^{-1}
Energy Loss per Year 87.99	Energy Loss per Year 36.10 kWh	Energy Loss per Year 35.036 kWh

Floor

Uninsulated House	Building Code minimum prior to 31/10/07	Building Code minimum after to 31/10/07

R=0.78	R=1.3	R=1.3
h=0.00668	h=0.004006	h=0.004006
dQ/dt =-10.256	dQ/dt = -6.153 Js^{-1}	dQ/dt = -6.153 Js^{-1}
Energy Loss per Year 89.84	Energy Loss per Year 53.90 kWh	Energy Loss per Year 53.90 kWh

Windows

Aluminium frame single glaze	Regular double glaze	High Performing double glaze
R=0.15	R=0.26	R=0.48
h=0.157	h=0.0901	h=0.0491
dQ/dt = -53.280 Js^{-1}	dQ/dt = -30.58 Js^{-1}	dQ/dt = -16.63 Js^{-1}
Energy Loss per Year 466.73kWh	Energy Loss per Year 267.88 kWh	Energy Loss per Year 145.68 kWh

Energy Loss per year of varying standard of insulation.

Uninsulated house with Aluminium single glazed windows looses 679 kWh of energy per year

Building regulations prior to 31/10/07 with single glazing looses 584.75 kWh of energy per year.

Building regulations after 31/10/07 with regular double glaze (this is currently the minimum standard for windows) looses 378.046 kWh of energy per year.

New Zealand has a total of 1,502,965 houses, which in total consume 12,417.0 GWh per year, 31.95% of the total energy consumption – 38,862 GWh. The 29778 houses built in 2007 and 2008 are compliant with the new building standards for wall, roof and floor R values, which in total consume 11.26 GWh. 16% of the housing stock has no insulation. 2% are new houses and have full insulation. This remaining middle bracket ranges from very little insulation up to the 2007 standard. We will take the average energy loss for these houses to be the average of 679 kWh and 584.75 kWh. This gives us 640.9 kWh as an average consumption for this bracket

697*0.16 + 640.9*0.82 + 378.046*0.02 = 644.6 kWh

This is the average energy consumption from heating in the average house over a year.

The average energy consumption of the not fully insulated houses is (this represents the average consumption through heating of the houses that could be improved with insulation).

(697*0.16+640.9*0.82) /0.98 = 650 kWh

Because retrofitting of wall insulation is an unreasonable expectation of the New Zealand public we will consider the savings that could be made by installing ceiling, floor to the current standard and double glazing. The energy usage by a house with wall and floor insulation and double glazing is (21.23+87.99+53.90+267.88) = 431 kWh. If all the houses with substandard insulation are insulated to this standard the average energy consumption on heating would drop to 431*0.98 + 378.046*0.02 = 429.94 kWh.

This represents a saving of (644.60-429.94) = 214.66 kWh per year per house. This is an overall decrease in energy consumption of 214.66 * 1 502 965 = 322626466.9 kWh = 322.6 GWh. This is a substantial decrease but it would require an extensive insulation program which would need to be substantially funded by the Government. The average costs of this insulation program per house is

2 Compact Florescent Bulbs

Incandescent bulbs, as are fitted in most NZ houses currently are hugely inefficient, they operate like a resistor, and thus they convert a hugely greater proportion of their supplied energy into heat rather than light. Energy saving, 'compact florescent bulbs' produce light by running current through a gas, causing shifts in electron energy levels, which results in emission of photons, thus light is produced, and no energy is wasted through heat production. This means that the required wattage for a florescent bulb is much smaller (aprox 25%[3]) than that of an incandescent bulb producing the same light intensity. We suggest that requiring all regular bulbs to be replaced with florescent bulbs is a reasonable request as an energy saving measure. Statistics show that 12% of residential energy consumption (7630kWh per annum) is through lighting[4]. Thus calculations as follows:

7630*0.12 =915.6 kWh

(We assume as a reasonable generalisation that all bulbs are currently incandescent)

0.75*915.6 = 686.7 kWh

Thus replacing all light bulbs with energy saving florescent light bulbs would result in an energy saving of 686.7 kWh per year.

3 Water Heating

Water heating is a large user of energy in the home. We decided that because of the large proportion of energy used in this area, any savings we could make would be significant in reducing our overall household energy useage. To model the energy loss from a hot water cylinder we will once again use Newtons law of Cooling. This states that the rate of energy transfer is proportional to the difference in temperatures. For our analysis we assume that energy will always be put into the hot water cylinder to keep the temperature constant at 55°C and the energy lost from the hot water cylinder will not heat up the surroundings of the cylinder in the house significantly. This means for our analysis the loss of energy from the cylinder will be a constant rate.

$\frac{dQ}{dt} = h\,.A\,(T_{outside} - T_{inside}) \quad h = \frac{\Delta Q}{A.\Delta T \Delta t} \quad R = \frac{\Delta T}{\Delta Q}$ so $h = \frac{1}{R\,A\,\Delta t}$

For a time of 1 second (this will give us energy loss in Watts, Joules per second)

[3] www.energystar.gov/index.cfm?c=cfls.pr_cfls
US department of Energy
[4] www.med.govt.nz/templates/multipageDocumentTOC_41143.aspx
Ministry of economic development

An uninsulated hot water cylinder has an R value of 3 while an insulating wrap around a hot water cylinder adds an extra 2.97 to this. Area of a hot water cylinder (smallest surface area for a 180L tank). This was found by differentiating the surface area function of a cylinder) is $3.011m^2$. Our change in temperature is from a water temperature of 55°C to an inside temperature of 18°C

Uninsulated Cylinder

R= 3

h = 0.1107

$dQ/dt = -12.332Js^{-1}$

This corresponds to 129.633kWh per year loss from each houses' cylinder

Insulated

R = 5.97

h = 0.05560

$dQ/dt = -6.194406\ Js^{-1}$

This is 54.263 kWh per house for a year

This is a saving of 75.37 kWh per household

4 Habitual Changes

Power shortages of the past, caused by low water levels in our hydro lakes, have lead to the threat of brown-outs in the winter months when power consumption is highest. Situations where this has been the case, such as the power shortages of 2003, have seen the government call upon the NZ public to save and preserve electricity. It has been demonstrated that the NZ population is prepared to save 8% of their residential electricity in times of need. If the government made campaigns urging power savings these reductions could possibly be once again met. This saving is 8% of 7630 kWh per household.

Total Savings

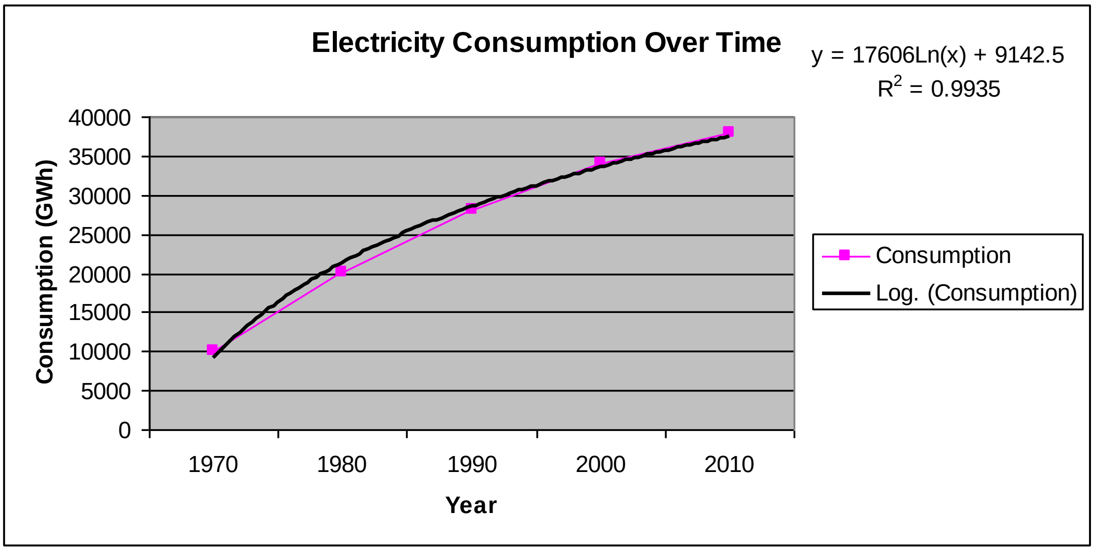
This 4 step plan will save overall 2380.8 GWh

This is made up of (214.66+686.7+75.37+0.08*7630) = 1587.13 kWh per household.

Multiplying this by 1 500 000 households gives an overall saving of 2380.8 GWh per year.

Electricity Consumption over Time

The total output of power stations in New Zealand to the national grid is 40000GWh, compared to the consumption of 38000GWh.



We added a logarithmic regression line to the plotted data which came out with an R correlation of 0.9935. This means that 99.35% of the variation in the change in consumption is dependant on the change in year. Only 0.65% is due to other factors. However, looking at the graph we can see that the graph does not fit exactly. Over time the log bends downwards at a greater rate than the given data. This means that a prediction over a long period of time will be lower than the actual rate of consumption at that time. Also, we do not know what the consumption rate is in 2010, so we used the 2009 consumption figures in place of the 2010 consumption in order to preserve the change in x axis. Thus actual consumption for 2010 will be higher than what we have taken into account.

Prediction for the date in which New Zealand will out consume its production of electricity using the logarithmic equation:

$y = 17606\ln(x) + 9142.5$

where y = the consumption in GWh and x = the number of decades after 1960 given that the production is 40000GWh maximum, the time we exceed our electricity generation will be when consumption is 40000GWh.

40000 = 17606ln(x) + 9142.5

30857.5 = 17606ln(x)

1.752669544 = ln(x)

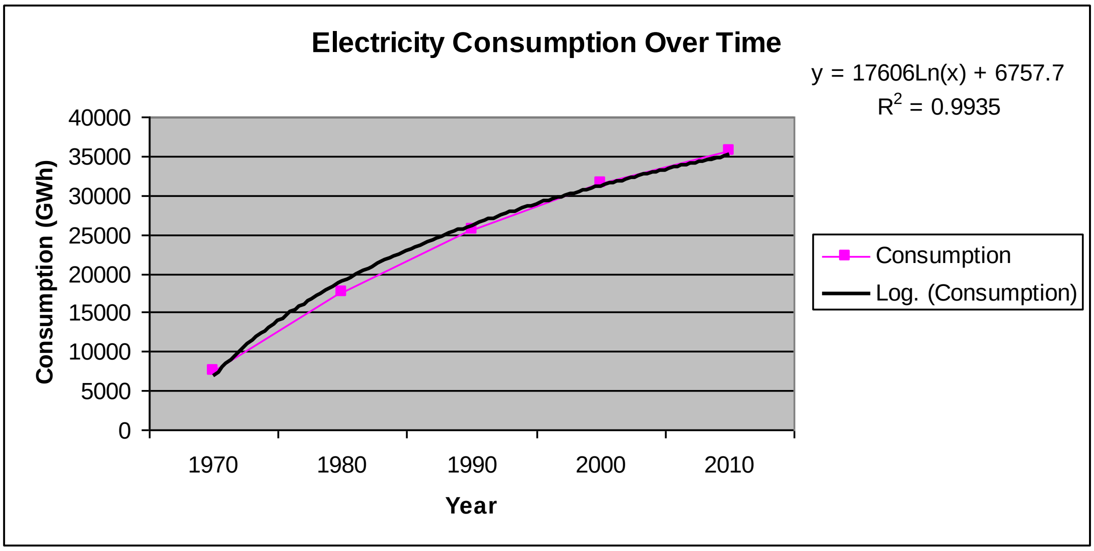
x = 5.769985 = 5.8(2sf)

1960 + 58 years = 2018

This estimate is a few years too high, however, as the log graph is decreasing at a greater rate than the consumption over time.

Using the Energy Saved as a Constant

2384.80GWh is the amount that we have calculated we could potentially save, thus we can take this number as a constant off the equation from above.



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The new equation would therefore be:

y = 17606ln(x) + 6757.7

This graph is the above graph with the constant (2384.8GWh) removed. This will not affect the gradient of the trend line. This assumes that over time the increase in consumption would be the same each year after the changes are made, as if the changes had not been made. However, all we have done is change the constant. This may not be realistic as the energy efficient light bulbs will ensure that as more light bulbs are placed, that consume less electricity than the previous bulbs, the consumption will increase at a lower rate than predicted by our new, modified, trend. Thus, for short term predictions this equation may be quite appropriate but will decrease in accuracy over time.

Prediction using new equation:

40000 = 17606ln(x) + 6757.7

33242.3 = 17606ln(x)

1.888123367 = ln(x)

x =6.606958= 6.6(2sf)

1960 + 66 years = 2026

This new prediction means that we will have eight more years without building another power station, however, ultimately we will need to build another power station.

Using the Energy saved as a Percentage

Using the amount we could save stated above, which is 2384.80, we worked this out as a percentage of the total consumption of 2010. we then took this percentage and extrapolated it through to the time at which we will need to build another power station. This gave us a new trend of:

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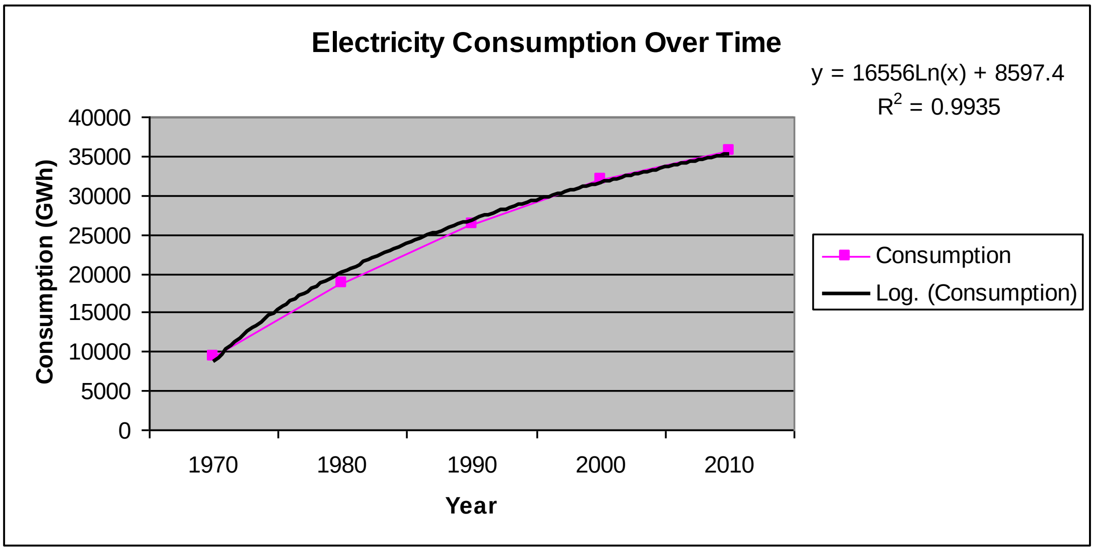
y = 16556ln(x) + 8597.4



This new trend line had both a different gradient and intercept to the previous function. This takes into account over time that the building of new houses will be more efficient and thus the consumption saved will increase proportionally to the increasing consumption. This means that over time, larger predictions will be more accurate than when using the other trend line.

New prediction:

40000 = 16556ln(x) + 8597.4

31402.6 = 16556ln(x)

1.896750423 = ln(x)

x =6.6642034= 6.7(2sf)

1960 + 67 years = 2027

This date is very close to the previously predicted value. This means that as there is very little variation between the trends, this prediction is therefore quite reliable. The graph lines both have high R^2 values, thus making these trends even more reliable. The latter trend line with the changed gradient will possibly be more reliable over time, as the gradient is changed as well as the y intercept.

Thus we predict that the year we will definitely require a new power generation facility is 2027. This prediction can only be accurate assuming that the total generation of electricity will be 40000GWh maximum. As this figure is to only one significant figure, it is a rough estimate and therefore has the potential to be unreliable.

Conclusion

Using our four point plan we can delay our requirement for extra electricity generation by eighteen years from now. A power plant will still be required in the long run.

Discussion – Costs vs. Benefits

Considering our calculation that our maximum energy saving measures would prolong our requirement for a new power generating facility by only eighteen years, we must consider whether the political and economic ramifications of implementing our four point program in reality outweigh the benefits.

Most economically significant in our plan is the requirement for reasonably extensive insulation retrofitting. The predicted cost of double glazing (the most significant home modification) alone, would be approximately $5000 per house,[5] thus a significant financial cost, falling upon the government. Compulsion regarding home modification and the way the public live their lives would never be met with open arms by the voting population. This means that unless full political guarantee from all parties was attained the legislation that this plan would require would be political suicide by the government. When we consider that a large proportion of our savings comes from the insulating component of the plan, any modification to this aspect could cause a huge decrease in the amount of energy saved and potentially cause the time and delay on power station construction, to be decreased significantly. Any political implementation of a program which requires such dramatic changes to private residences is unlikely to be implemented. In reality it is potentially more cost effective to pay for a new power generating facility now than delay for the eighteen years this plan would ideally result in.

[5] http://www.infometrics.co.nz/article.asp?id=4158 [Article – Gareth Morgan]

The idea that the residents of New Zealand save eight percent of their power as they did during 2003, which was the last major power shortage, is unrealistic. The reason why New Zealanders saved this amount was due to the fact that the government played television advertisements pro saving power responded in kind through fear of blackouts. This would not happen over a period of eighteen years as the public would be reluctant to forgo their habits and lifestyle so easily. Another problem with the saving of 8% of the total power generated the fact that having fitted energy saving light bulbs, the act of turning off unused light will not save the same amount of electricity as previously saved in 2003.

Our prediction assumes that the maximum amount of electricity we can generate is 40000GWh. However, during 2003 for example the lack of water needed by hydro-generation facilities impacted upon this number. It dropped our maximum generating capacity by 7% - a rather large amount. Our trend gives no leeway for a problem such as this. Upon becoming close to the eighteen year mark the stopping of even one hydro-generation facility, or any other for that matter, would result in a power shortage. It would be unrealistic for the country to have this worry upon them for the years leading up to 2027.

The potential benefit of this plan is that we would have eighteen years for energy efficient technology to improve and become more cost efficient. This could potentially include modifications to current power generating facilities to increase the electricity generated, without the need for a new power plant. Over these years the decreasing cost of installing energy efficient technology into everyday homes could potentially become a lot cheaper, thus more cost effective than building new power generating facilities. We have not taken into account for the fact that it is impossible to renovate over one million homes immediately with our four point plan. This means that we would potentially consume more electricity allows for, however, if these modifications happened over a period of 18 years , which is realistic as long as the consumption of the households does not exceed the 40000GWh maximum.

In reality, residential power consumption is only one third of New Zealand's power usage. The potential savings which are quite significant as a proportion of home power usage are diluted when reflected on the national grid. To truly assess our ability to delay the necessity for extra power generation, the consumption of commercial and industrial sectors would have to be analysed, and a similar program which provided reasonable cuts, while not significantly affecting our economy should be implemented to provide savings proportional to those in the public sector. This could potentially mean that our ability to save is dramatically increased (by as much as 200%), this could mean a much longer time delay. In reality, like in the residential sector, any cuts this significant would be detrimental to our economy and therefore not accepted by businesses.