CONFERENCE PAPER

No. 103 (2002)

Benefit-cost Analysis of Thermal Insulation in Australian Dwellings

**Nigel Isaacs, Tony Marker,
Ian Page and David Wallace**

Presented at the ICEC Conference,
Melbourne, 14-18 April 2002.

This work was funded by the Australian Building Codes Board
and the Australian Greenhouse Office.

ISSN: 0111-7505

Benefit-cost analysis of thermal insulation in Australian dwellings.

Nigel Isaacs, [1] BE, MBldgSc

Tony Marker, [2] PhD

Ian Page, [3] ME(Civil), MIPENZ

David Wallace,[4] FAIQS

The development of a financial model and software tool for assessing space conditioning energy efficiency measures in houses is described. A large number of options were modelled and the paper describes how the net benefits of energy and carbon emission savings were assessed, and presented in the tool.

[1]Manager, Energy and Environment, Building Research Association of New Zealand, Porirua City, 6220, New Zealand, [2]Manager, Energy Efficiency, Australian Greenhouse Office, Canberra, ACT 2600. [3]Building Economist, Building Research Association of New Zealand, [4]Managing Director, Northcroft (Australia) Pty Ltd, NSW 2089.

1 INTRODUCTION

This paper summarises the approach used in the development of a financial tool for the study of the costs, benefits, energy savings, and carbon emission savings, of thermal insulation in Australian houses. Most cost engineering projects involve the analysis of only a few alternatives in one location. This project differs from these in two ways:

- The large number of design alternatives that had to be assessed in different locations,

- The cost data is an input into a cost-benefit study on reducing energy use in housing.

The client was the Australian Building Codes Board (ACBC) and the Australian Greenhouse Office (AGO). When the former proposes changes to the Building Code of Australia it has to consider the economic implications of the changes. Their brief, in conjunction with the AGO, was to develop a tool to assess the financial implications of mandatory changes to space heating efficiency measures in houses, and to quantify potential energy and carbon emission savings.

A number of house designs were selected and their space conditioning performance was assessed, across several climate zones. Over 4 million combinations of house design, location and insulation were obtained from the energy model runs. These results were used as input into the financial tool.

2 HOUSE SELECTION

The tool development considered a range of house designs that are typical in Australia, in various cost locations. The house selection involved detailed analysis of over 400 houses recently constructed in Victoria and ACT, an analysis of the Australian Bureau of Statistics data on new houses, and examination of specialist house designs. The search was narrowed to 17 designs from which six designs were finally selected for use in the modelling:

1. **Detached House –– Small Single Storey:** A standard small house.
2. **Detached House – Medium Single Storey:** Selected as very close in floor area to the 50th percentile of Australian houses.

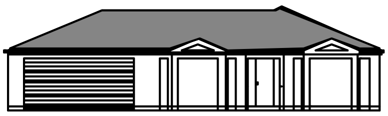
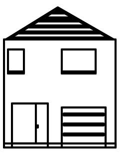
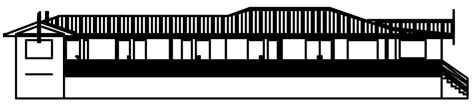
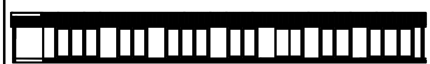
3. **Detached House –Large Two Storey, Attached Garage:** Selected as being very close in floor area to the 75th percentile of Australian houses. Two storey houses have different thermal performance to single storey.

4. **Townhouse – Two-storey, Two Neighbours, Attached Garage:** Selected as representative of few wall areas exposed to the weather and hence a relatively low sensitivity to the benefits of wall insulation.

5. **Detached House - High Ventilation Design:** An archetypical "Humid Tropical" house with long plan form, cross flow ventilation and elevated construction.

6. **Detached House - Passive Solar Design:** Selected as reasonably thermally efficient, sensitive to orientation,.

Figure 1 provides illustrations of the six houses along with Gross Floor Area (includes garage, etc) and Conditioned Floor Area.

		
House 1: Small Single Storey (173 m² GFA, 143 m² CFA)	House 2: Medium Single Storey (251 m² GFA, 168 m² CFA)	House 3: Large Two Storey (294 m² GFA, 203 m² CFA)
		
House 4: Townhouse (133 m² GFA, 84 m² CFA)	House 5: Cross Ventilated Tropics (156 m² GFA, 138 m² CFA)	House 6; "Passive Solar" (172 m² GFA, 152m² CFA)

Summary Figure 1: House Designs

3 CLIMATE/ COST LOCATIONS

Table 1 lists the 12 Climate Zones used in the study. Climate records from each zone were used for energy modelling, and cost data was also obtained for each zone.

Table 1 – Climate Zones and Cost Regions

#	Location	Climate Zones - Descriptive
1	Darwin, NT	Hot humid summer – warm winter
2	Longreach, QLD	Hot dry summer – warm winter
3	Townsville, QLD	Hot humid summer – warm winter
4	Brisbane, QLD	Warm humid summer – mild winter
5	Perth, WA	Warm temperate
6	Sydney, NSW	Warm temperate
7	West Sydney, NSW	Mild temperate
8	Mildura, VIC	Hot dry – cool winter
9	Adelaide, SA	Mild temperate
10	Melbourne, VIC	Mild temperate
11	Canberra, ACT	Cool temperate
12	Hobart, TAS	Cool temperate

4 COST DATA

The information on costs for energy efficiency alternatives was specifically prepared for the project by Northcroft (Australia) Pty Ltd for the house construction, and by Energy Partners for fuel prices.

4.1 Insulation variations

The insulation combinations are in Table 2. The roof/ ceiling had six levels of insulation (including nil insulation), each wall type had four levels of insulation, and the floors had two levels (concrete floor) or three levels (timber floor). As well, four types of window were considered, and four types of shading.

Table 2: Insulation Brief Descriptions					
Description (Wall/Case)	**A / 1**	**B / 2**	**C / 3**	**D / 4**	**E / 5**
Wall constructions	Weatherboard	110mm Brick Veneer	Cavity Brick	Concrete Block	
Wall Insulation Type 1	Reflective Foil	Reflective foil	30mmPolystyrene	28mm Polystyrene	
Wall Insulation Type 2	R1.5 fibreglass	R2 fibreglass	40mm Polystyrene	38mm Polystyrene	
Wall Insulation Type 3	R2 fibreglass	R2 fibreglass + foil	50mm Polystyrene	47mm Polystyrene	
Roof	Foil under tiles.	R1 Ceiling	R3 Ceiling	R5 Ceiling	Foil + R3 Ceiling
Suspended floor	Dropped foil	R2 fibreglass			
Slab-on-grade floor	25mm Polystyrene to 450mm depth				
Glazing	Single clear 6mm (SG Clr) Aluminium frame	Single tinted 6mm (SG Tint) Aluminium frame	Double Clear (DG Clr 4/8/4) Thermal broken frame	Double Low-E (DG,LE,HI) Thermal broken frame	
Shading	No Eaves	600mm Eaves	Fabric awnings	3.6m Verandah	

4.2 Insulation Prices

Costing of insulation used traditional elemental cost methods on six designs in 12 cost locations, a total of 72 combinations. For each combination cost data was provided for External walls, Internal walls, Roof, Ground floor, Windows and Shading. The process was complicated by three factors:

- Some locations are quite isolated, see Table 1, and detailed insulation cost data was not readily available. In these cases the State capital prices were used and adjusted to local prices, based on related construction work in the region.

- Some energy efficiency measures such as eaves and verandahs are not readily placed on all the house designs, and judgements were made on how much of the perimeter would be covered.

- Some energy efficiency provisions, e.g. double glazing, are not widely available and if mandatory efficiency measures are introduced, production economies of scale may reduce unit prices. It was decided to use current unit prices, but to have the ability in the financial tool to adjust unit prices, as required in the future time.

Typical insulation prices varied by 15% between the capital cities, and some isolated locations had prices 28% higher than their State capital.

4.3 Energy prices

Electricity and natural gas prices were obtained for each cost location from published tariffs of energy suppliers, and the lowest price supplier in the region was selected. Marginal prices were used, i.e. 'Fixed" or 'daily charges' were not included (as they have to be paid regardless of insulation levels). Many domestic tariffs are stepped, and the unit price used was the lowest of these. The prices ranged from 7.7c/kWh to 13.0 c/kWh (excluding GST) for electricity, and 2.8c/kwh to 7.1 c/kWh for gas, depending on location. As prices are likely to increase in the future the financial tool has provision to adjust these.

4.4 CO_2 Intensity Factors

A direct relation exists between energy consumption and CO_2 emissions, the so-called CO_2 intensity factor. These vary by location, depending on the type of generation, and line losses. The typical ranges are 0.65 to 1.3 kg CO_2/kWh for electricity, and 51 kg CO_2/GJ for gas, based on AGO studies. The financial tool quantifies the amount of energy saved for each insulation combination, compared to the zero insulation case, and hence the tool is readily able to provide carbon saving volumes. CO_2 intensity factors are likely to change over time, and the financial tool allows for these to be adjusted, by location.

5 FINANCIAL ANALYSIS

5.1 Analysis approach

The above data on costs and energy consumption was the input into the financial analysis, which was carried out by BRANZ. A cost benefit analysis approach was adopted, using the present value methodology. This enabled financially optimal solutions to be identified. A financial analysis software tool was developed to present this information. The tool also shows CO_2 emission savings, and their trade-off with costs.

5.2 Financial analysis

The present value method was used, in which costs are brought to current dollar values using discounting methods. Two main categories of costs were included:

- **Initial costs**: The costs of insulation, special glazing, and shading.
- **Energy costs:** The on-going costs of energy consumption within the dwellings. These costs are discounted to present values in recognition of the time value of money.

The energy consumption within a house varies for each combination of insulation, glazing and shading and there is a trade-off between initial expenditure on insulation, and on-going expenditure on energy. The present value method allows these trade-off to be quantified in a consistent manner. The formula used is given in Equation 1:

$$PV_{Total} = \$_{Insulation} + PV_{Glazing} + PV_{Shading} + \sum_{t=1}^{n} \frac{(1+e)^t P_o}{(1+r)^t}$$

Equation 1

where:

$\$_{\mathbf{Insulation}}$ = Cost of insulation. (i.e. cost of installation + cost of materials)

PV $_{\mathbf{Glazing}}$ = The additional initial costs of glazing options, additional to ordinary glazing. For double-glazing, the replacement of the window is at 30 years (default, can be changed) and this replacement cost is discounted by the SPPWF (Single Payment Present Worth Factor), as shown in Equation 2:

$$\mathrm{PV}_{\mathrm{Glazing}} = \$_{\mathrm{DoubleGlazingPremium}} \times (1 + \mathrm{SPPWF}(r,30))$$

Equation 2

PV $_{\mathbf{Shading}}$ = The costs of the shading options, additional to no shading. The full cost of options, 600 mm eaves, awnings, and 3.6 m wide verandahs, was included. For awnings only, a default 25 years lifetime has been assumed, and the discounted replacement cost included in the present value, as given in Equation 3:

$$\mathrm{PV}_{\mathrm{Awnings}} = \$_{\mathrm{Awning}} \times (1 + \mathrm{SPPWF}(r,25))$$

Equation 3

$\mathbf{P_o}$ = Initial energy cost.

r = discount rate

e = energy price real escalation (i.e. the rate of escalation above the general inflation rate).

t = time period of the analysis (t = 1, 2,3,……n)

SPPWF(r,T) =Single Payment Present Worth Factor, at discount rate r, at year T.

n = period of analysis. The number of years over which energy savings were discounted.

For a given house, in a particular climate and cost zone, the present value can be calculated for all combinations of insulation, glazing and shading, and the combination with the lowest present value is the optimal combination from a financial viewpoint. It is often useful to present results in terms of Net Present Value (NPV), where the base case is the zero combination i.e. no insulation, plain glazing and no shading. In the financial tool both values were used.

The NPV is defined as the difference between the Present Value for the base case (zero insulation, plain glazing, no shading) and the Present Value for the case under consideration with the specific combination of energy efficiency options as given in Equation 4:

$$NPV_k = PV_{Zero\ Insulation, Single Glazing, No\ Shading} - PV_{Energy\ Efficiency\ Combination\ k}$$

Equation 4

The combination with the lowest PV and the highest NPV are identical, and give the highest financial return over the life of the building. However, all measures with a positive NPV are cost-effective under the given financial assumptions (e.g. discount rate, lifetime etc).

5.3 Discount and Life time Defaults

The financial software tool developed allows for a number of the analysis variables to be altered, including the discount rate and period of analysis. However the default values had to be specified. From a dwelling owner's perspective, it is logical to view the capital cost of built in energy measures as an increase in capital borrowings. Thus assuming a fixed interest rate of 7.5% and a CPI inflation rate of 2.5% gives a real discount rate of approximately 5%.

An alternative viewpoint is that the homeowner is forced to invest in energy efficiency through mandatory building code requirements and loses the opportunity to invest elsewhere. The opportunity cost is the rate of return from alternative after tax investments. Currently these investment returns are probably below 5% after tax.

From a social perspective, the discount rate should reflect society's preference to consume now rather than later, which can be measured by the ten-year government bond rate because this is the rate that just overcomes this preference. Currently, the 10-year bond rate is about 5.5% nominal and over the past 10 years has averaged 5% real.

The "Regulatory Impact Statement 2001-1" (ABCB 2001) used a discount rate of 5% and the financial analysis provided for periods of 25 years and 50 years. The former is intended to present financial outcomes from a private perspective, the latter from a longer-term social perspective.

The default discount rate has thus been set at 5% in the analysis tool, and the default analysis period set to 40 years, as an intermediate value. The user, as required, can alter all defaults.

5.4 Omitted costs and benefits

The financial analysis omits some costs that would be included in a full economic analysis. For example the following have not been included:

- **Appliance capital and maintenance costs:** The capacity of heating and cooling appliances will vary with the level of insulation, as will their maintenance costs. For example, reducing the temperature in an uninsulated house will require a larger appliance than would be the case in an insulated house. These variations in initial and on-going costs have been ignored.

- **Replacements of special glazing and shading:** Replacement period at years 30 and 25 (double glazing and awnings respectively) have been assumed. However subsequent replacements, and any maintenance costs have been ignored.

- **Multiple benefits of energy efficiency options:** The full cost of the energy efficiency options have been evaluated against the energy savings. In many cases the energy efficiency option will have other benefits. For example, eaves and verandahs greatly assist in weather tightness around windows and doors, they may be used for clothes drying, they may form an important 'outdoor' space for enjoyment when temperatures are high or rain is heavy, and verandahs provide a transition area into the house in the wet season.

- **Health benefits:** Warmer indoor temperatures in cold areas, and reduction in temperature swings in both cool and tropical regions can result in improve health status for occupants.

- **Moisture control**: Thermal insulation results in higher surface temperatures in cool locations, reducing the opportunities for mould and other moisture related problems.

6 FINANCIAL ANALYSIS TOOL

The financial modelling tool runs in Excel 2000 under Windows. The programme obtains data from an MS Access dataset. The data includes all insulation combinations for six houses in 12 climate zones, with both 17 hours and 8 hours of conditioning. The programme file size is approximately 36MB, and the Access dataset 36MB in size. Once ‘zipped’, the data file reduces to approximately 16 MB.

For each combination of:

- house type (6 types),
- climate zones (12 types),
- orientation (4 types),
- wall type(4 types),
- glazing (4 types), and
- shading (4 types)

the analysis tool provides data on the:

- energy consumption,
- present value and
- CO_2 saved

For 72 timber floor combinations of insulation, and 48 concrete floor combinations of insulation. This gave a total of 4,423,680 models, or 61,440 for each house in each location.

How can the user make sense of this mass of results? It was decided to provide various levels of information, ranging from detailed results for a specific house, climate and insulation combination, to summaries of optimal insulation combinations that maximise NPV or carbon savings.

The first screen (Figure 2) provides detailed results, based on the users selection of house and economic parameters, and the tool calculates and shows the present value, and other results.

Summary data is available on a screen accessed by the **Max Star Rating** button. This shows the 40 “best” insulation combinations for the selected house, for all wall types, floor types and locations. The "best" combinations are either maximum NPV or maximum Star Rating (least energy use, and maximum carbon saving), shown in two panels.

The **Unitcosts** button goes to the second menu of the analysis tool, which permits the user to change unit costs for energy, insulation, glazing and shading, the CO_2 intensity of electric energy, appliance efficiencies, and the default replacement periods for double-glazing and awnings.

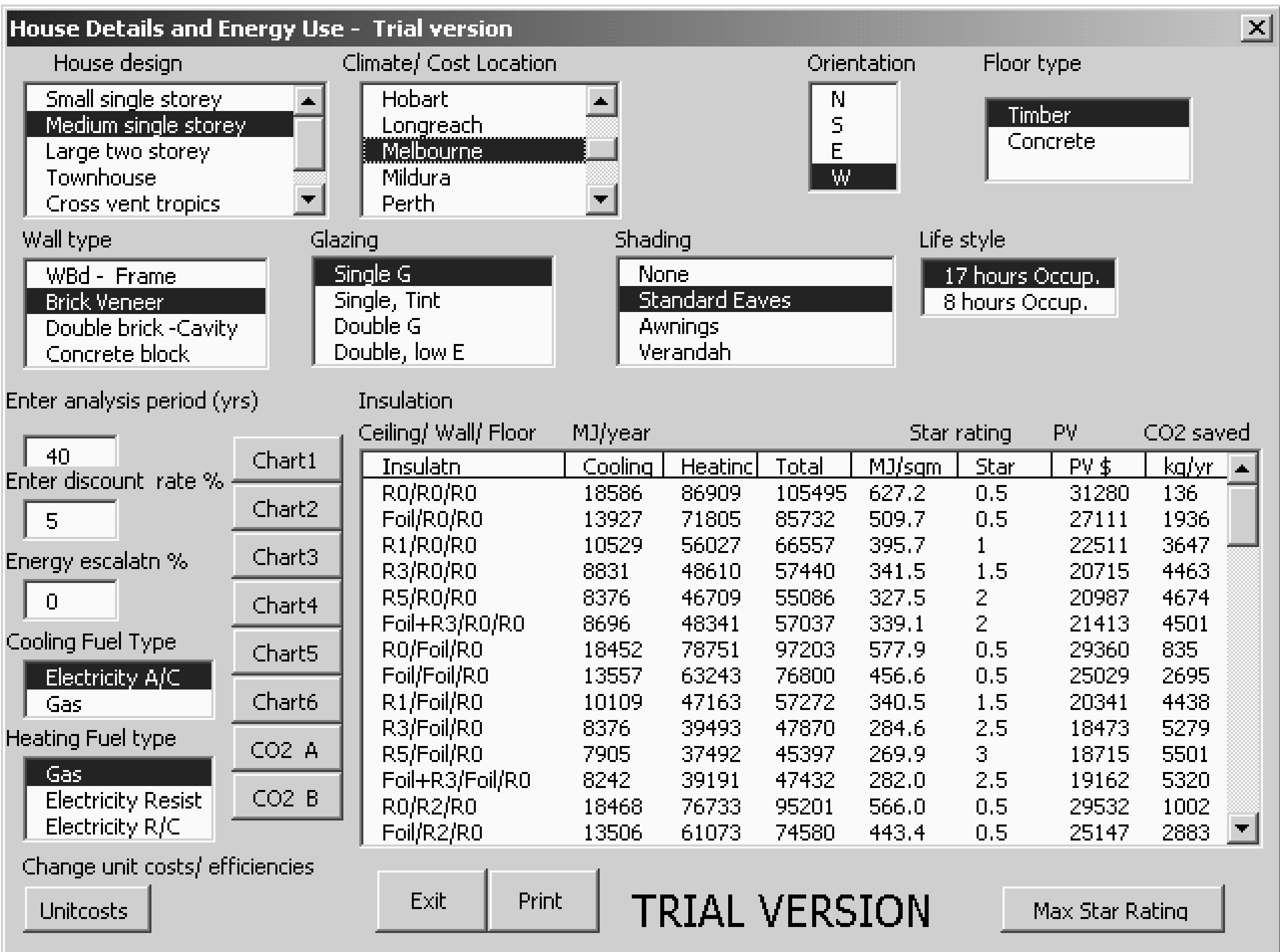


Figure 2: Financial Analysis Tool Data Entry – Screen 1

Back to the main screen, eight charts are available with increasing levels of summary results. When each chart has been selected and is being viewed, a 'button box' provides the ability to 'Print' the chart and data, or 'Return' to Screen 1. Three of these charts are now described.

Chart 3: Net Present Value (NPV) for each insulation combination (Figure 3), provides detailed information for a specific house. The base case is no insulation, single glazing, and no shading. The y-axis value is given by Equation 4.

Cases are ranked in descending order, so that insulation combinations on the left have the highest NPV. Some combinations have negative NPV, i.e. those combinations have net costs, or in other words, the value of discounted energy savings does not cover the cost of insulation.

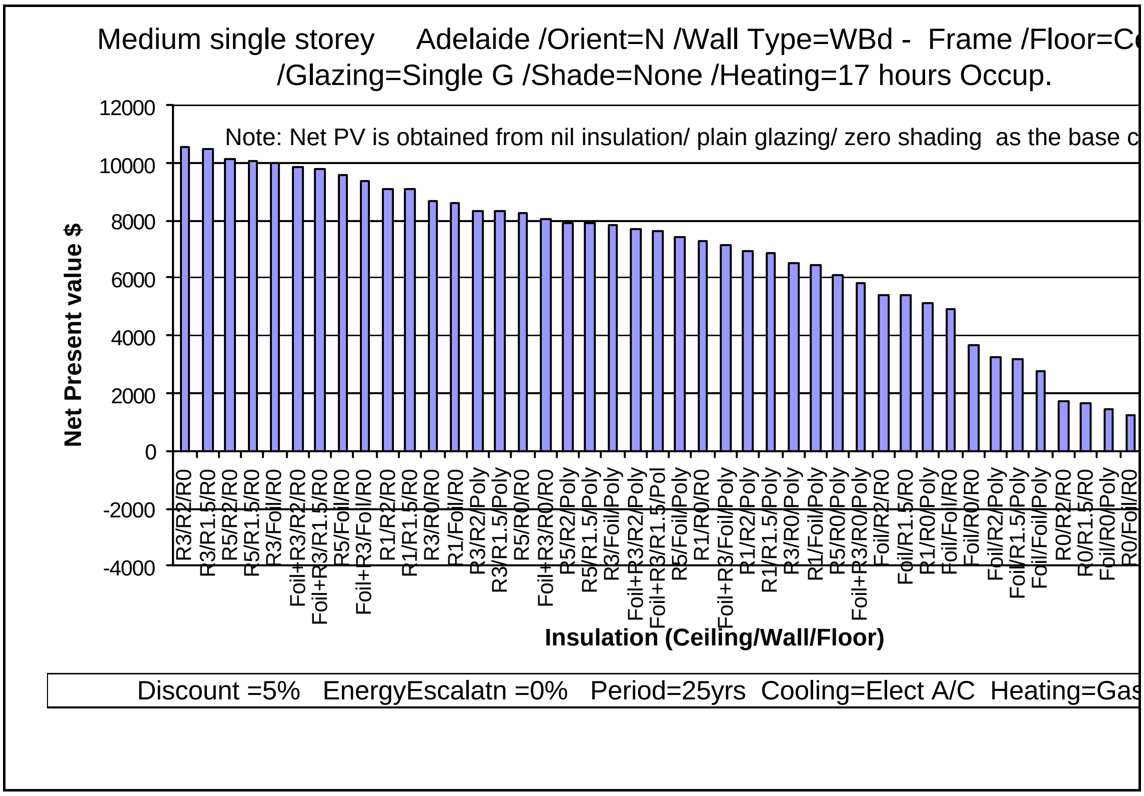


Figure 3: Example of Chart 3

Chart 5, (Figure 4) provides a wider range of data, and enables identification of insulation combinations with good energy performance (4 stars or more) with positive NPV. The desired selections are to the left of the four star line and above the x-axis. Some house designs in some locations do not achieve these criteria.

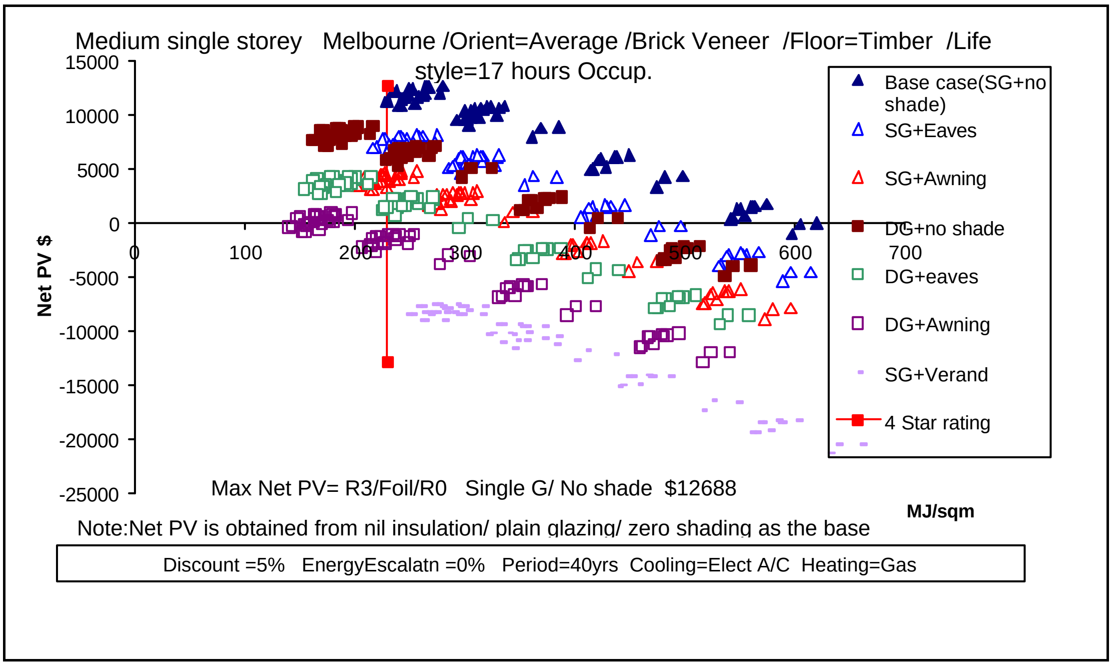


Figure 4: Example of Chart 5

The final chart **CO_2 A:** (Figure 5) is probably the most useful as it is a summary of optimal insulation combinations for maximum NPV and carbon savings. (A table of data can be printed with the chart). The lower line is the $ per kg of CO_2 saved for "outer envelope" combinations of insulation. This is the so-called "CO_2 supply" line and its derivation is discussed later. The $ amount is the NPV. The CO_2 saved line is below the x-axis for each insulation combination that has a positive NPV. Above the x-axis the cost of the insulation exceeds the discounted value of the energy savings and there is a net cost to save additional CO_2. This additional expenditure may be worthwhile if a carbon emissions tax regime is introduced in the future. The Y-axis represents the level of carbon tax that makes addition insulation economic.

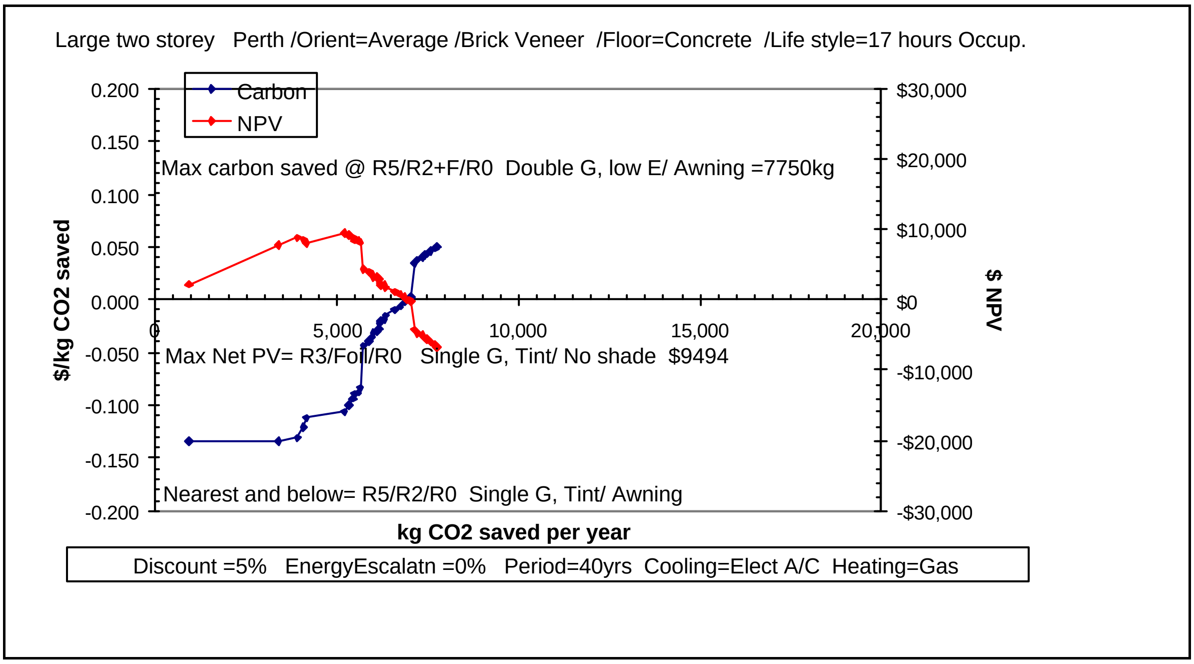


Figure 5: Example of Chart CO_2 A

7 CO_2 SAVINGS

The CO_2 supply curve, Figure 5, shows the unit cost per kg CO_2 saved plotted against annual CO_2 savings for one house. The vertical axis is the NPV divided by the CO_2 savings. However, there are two important considerations in its derivation:

- What volume of CO_2 savings should be used as the divisor?
- Carbon emissions charges should not be "double counted".

Firstly what volume of CO_2 savings should be used? The choices are:

- Annual CO_2 savings.

- Total CO_2 savings over the analysis period, e.g. over 40 years.
- Discounted CO_2 savings over the analysis period.

The first choice does not recognise CO_2 savings after the first year. The second choice assumes that CO_2 savings are equally valued in subsequent years. The third choice assumes that immediate CO_2 savings are of more value than distant savings. The third choice, is preferred, i.e. discounted CO_2 savings are used as the divisor. The reasoning is as follows:

Suppose decision makers wish to increase the amount of insulation beyond that indicated by the combination with the maximum NPV, or the combination closest to zero NPV. How can they justify that decision in financial terms? They can justify it in terms of a normal cost-benefit analysis in which a value is put on CO_2 savings, say a hypothetical world trading price in $US per tonne of carbon. The argument is that more is spent now on insulation to reduce the future expenditure on carbon emission rights. This purchase of carbon rights is expected to be in blocks, possibly for periods of 5 years, and occurs at year 0, 5, 15, 20, and so on. Hence this expenditure is similar to any other future cash flow, and needs to be discounted. In present value terms the equation for an individual house is given in Equation 5:

$$\$_{EnergyEfficiency} - PV_{EnergySavings} - PV_{CO_2Savings} = 0$$

Equation 5

In other words, this equation suggests that the justifiable amount of expenditure on energy efficiency options (insulation, glazing or shading) is equal to the value of the discounted energy savings plus the discounted value of CO_2 savings, over the analysis period e.g. 40 years. CO_2 savings are discounted because they represent a cash flow over a period of years as in Equation 6.

$$PV_{CO2Savings} = \sum_{t=1}^{N} \frac{P_{CO_2} \times Vol_{CO_2Savings}}{(1+r)^t}$$

Equation 6

where P_{CO2} = Unit price of CO_2 emissions ($/kg CO_2)

$Vol_{CO2Savings}$ = kg of CO_2 saved per year

It is likely that the unit price of CO_2 emissions will change over time. However for simplicity we assume it remains constant. Hence in Equation 6 we are effectively discounted the volume of CO_2 savings. We do not know the hypothetical trading price for CO_2 emissions. Instead the financial tool shows what the trading price needs to be at various insulation levels, to satisfy Equation 5.

The second consideration was "double counting." This would arise if the energy prices used in the tool included carbon tax, so that in Equation 5 the carbon charge is included in both the $PV_{\text{Energy savings}}$ term and $PV_{CO2Savings}$ term. The best solution is to set the energy prices in the tool net of any carbon charge.

8 SENSITIVITY ANALYSIS

This section explores the sensitivity of the analysis to changes in the base financial assumptions.

8.1 Discount rates, time period, and appliance efficiencies.

Figure 8 shows selected sensitivity runs for the medium sized, single storey, brick veneer house on a concrete slab in one location, Melbourne. The parameters changed were:

- Discount rates, from 1% to 11%, in 2% steps.
- Period of analysis from 5 to 70 years, in various steps.
- Energy escalation rate from –2% to + 3%.

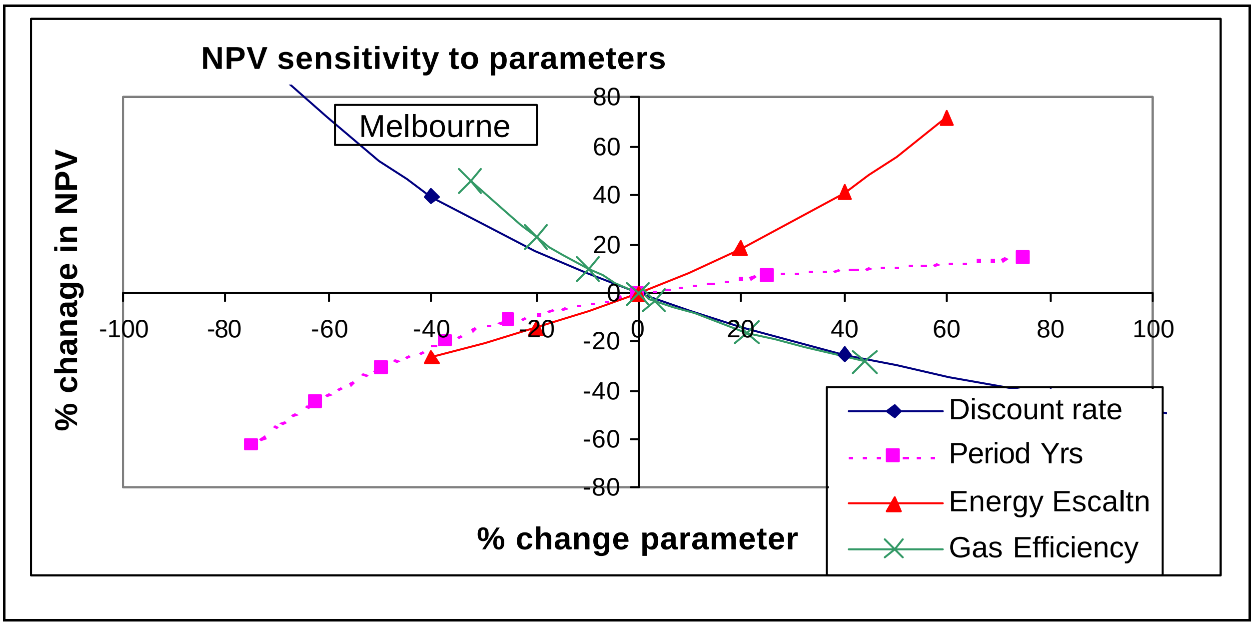


Figure 6 Sensitivity Of NPV To Changes In Various Parameters in Melbourne

- Gas heating efficiencies from 41% (1 AGA Star) to 88% (5 AGA Stars), in Star steps.

The chart show the change in maximum NPV due to variations in the selected parameters, varied one at a time from the base case. The base case is the insulation combination with maximum NPV, for 5% discount rate, 40 years analysis period, zero escalation in real energy costs, and 61% efficiency in gas heating appliances. The vertical axis is the NPV and the horizontal axis is percentage changes in the parameters.

For example a 70-year period is a 75% increase on the base case and in Melbourne this causes the NPV to increase by about 14%. A discount rate of 9% is an 80% increase on the base case, ((9/5)-1)*100, and causes the NPV to reduce by about 42%.

The steeper the curves the more sensitive the NPV is to changes in that parameter. The curves indicate the results are sensitive for the following changes:

- **Analysis years, at the shorter analysis periods**: However after about 40 years the curve becomes quite flat.

- **Gas appliance efficiencies in the cooler climates:** A change from a low star rating to higher ratings has a large influence in Canberra and Melbourne, and is not quite as "elastic" in Sydney and Brisbane.
- **Energy price escalation:** At 2% and 3% escalation the change to NPV is large.

8.2 Other variables

The tool allows the sensitivity to occupancy hours, glazing costs, and shading costs to be investigated. As expected reduced occupancy lowers the level of insulation that is optimal, typically by about one step. A reduction in double-glazing costs, due to scale economies, spreads the cost effectiveness of double glazing outside the hot and cold regions into some less extreme climate locations. If shading costs, such as verandahs are reduced by 50% in recognition of their other roles apart from shading, then they become cost effective in the warmer locations.

9 SUMMARY

The paper has provided summary output available from the financial analysis tool. The tool provides data on energy savings, CO_2 savings, initial costs and optimal insulation combinations. The displays enable the identification of the relatively small number of energy efficiency combinations for each location, house design, and floor type or wall construction. It enables trade-offs between net present values and carbon emission savings to be identified, and hence illuminate Government policy choices in the sustainable development of the Australian economy.

10 ACKNOWLEDGEMENTS

This work was funded by the Australian Building Codes Board and the Australian Greenhouse Office.