LEAST-COST ENERGY EFFICIENT DESIGN

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Optimal Value Engineering is a discipline that enables designers to specify the most cost-effective (least cost) design, depending on the specific project financial parameters. The "optimal design" process will produce the best building for the lowest cost.

An optimally designed new office building would be more comfortable than today's "typical" office, with better ventilation, temperature control and lighting, which would make it easier and healthier to work in. At the same time, an optimally designed building would have much lower energy use and operating costs than normal, giving dramatically reduced pollution and environmental impact, and making it more profitable co occupy.

Even better, this optimally designed building would have a lower construction cost and more usable space than a traditional building, so it would be more profitable to build and own.

The problem

It is virtually impossible to achieve such a building in New Zealand with the current style of property development. This is because developments chronically under-invest in design, so that architects and engineers have to skimp on their work to complete the job in little enough time to avoid a loss.

Unless designers are paid to do their job properly, and an energy efficiency specialist is included in the design team along with the quantity surveyor, the design methods that can give significant (capital and energy) cost savings must be ignored in the rush to just get the job done without losing money.

At the same time, energy inefficiencies are built in, because, to minimise design time, heating and cooling systems are normally oversized by significant amounts.

Oversized systems not only cost more, but also work less efficiently than correctly sized ones, as they work at a smaller fraction of their capacity (and farther away from their maximum efficiency point) more of the time.

In almost every commercial building of any size or complexity, there are flaws in the operation and control of the HVAC systems. This is another reason why oversizing of systems is so pervasive - if they are large enough, then they can overcome most of their failings by sheer brute force (even at extreme cost).

The solution

Optimised design of buildings (and other infrastructure) extends the value engineering done by quantity surveyors to all major design decisions, and considers the effects of interrelationships between components. Experience has shown char the energy systems (building envelope, lighting, and HVAC) are the areas where the most significant cost savings can be made.

Thus, integrating an energy efficiency specialist into the design team right from the start of the project can lead to a building which is simultaneously lower cost, more energy efficient, environmentally friendly and much more comfortable and productive to work in. The decision to optimise the design must be made at the very start of the project, because after the normal design contracts are let (for the normal prices), there is no time or incentive for the necessary extra design work.

The techniques that are used to optimise design include explicit thermal modeling, to account for the specifics of the building design. These allow the heating and cooling systems to be accurately sized for the real situation, rather than using rules of thumb. This explicit thermal modeling also provides accurate information for energy efficiency decision-making. It also measures the interrelationship between the design of the lighting, the building's envelope and its heating and cooling systems, so the design can be truly optimised.

Also, instrumented commissioning (diagnostic monitoring) actually measures the performance of the building's mechanical and electrical systems after they are installed, but before the building is occupied to make sure that everything works properly before the construction is accepted.

The result

Although these design techniques do add to the cost of design, for most significant buildings, they can also deliver capital cost reductions that more than cover the extra design costs. And they allow a much better building to be completed.

For example, a typically designed new 10,000m^2 office building would cost about $10 million to build and finish. The distribution of costs will be about as shown in Figure 1 below. (These data are from the U.S. construction costs handbook: "R. S. Means Square Foot Costs 1992". They are generally applicable to New Zealand as well.)

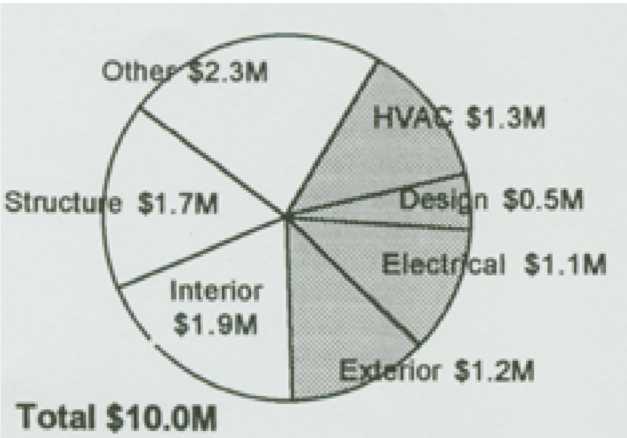

Figure 1 – Typical building costs

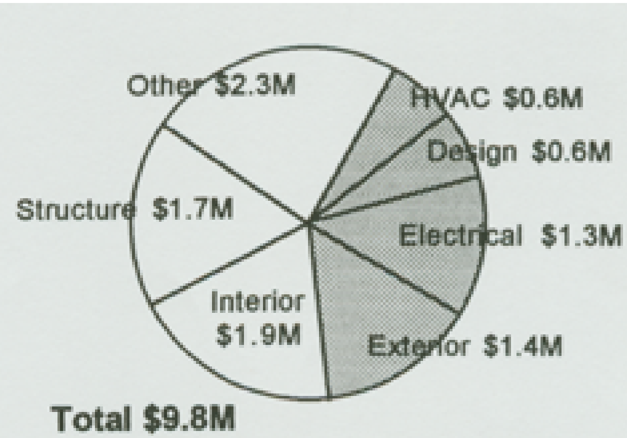

Figure 2 – Efficient building costs

In this building, the (1000 kW) HVAC system would cost about $1.3 million, and total design fees would be about $500,000 (of which about $120,000 would be for mechanical and electrical design). Such a building would use about 2 million kWh of energy per year, at a cost of about $200,000/year.

Conversely, an efficiently designed building (as shown in Figure 2, above) would integrate the improved design techniques described above (costing about $50,000 extra) and a number of energy efficiency techniques (costing, say $500,000 extra) and to reduce the HVAC system size to about 500 kW (saving about $750,000 there).

In net, the efficiently designed building would cost about $200,000 less to build, and would also use only about half as much energy (saving another $100,000/yr) as well as being a more comfortable and productive environment for its occupants.

Specifications for a similar building (though smaller, only 4,000 m^2) are given in Table 1. This also shows the estimated costs for all the equipment listed, from Rawlinsons New Zealand Construction Handbook, or E SOURCE reports.

Table 1 - Typical (4,000 m^2. eight storey) office building design specifications and sizes

Component	Standard design	Least-cost design	Long-term least-cost
Walls (1500 m^2) Roof (500m^2)	Uninsulated walls and roof	100 mm wall insulation, 150 mm roof insulation ($18K)	Probably 100 mm wall insulation, and 150 mm roof insulation ($18K)
Windows (650 m^2)	Single glazed, no restriction on size, placement, quality.	Double glazed, low emittance, solar control glazing. (+$60K)	Triple glazed, wavelength selective, argon filled, solar control glazing. (+$100K)
Ventilation (400 people, 2.8 m^3/s)	Fresh air supply only, to 7 litres/s per person. OR, no mechanical ventilation but operable windows.	VAV supply, mechanical exhaust through space heating heat pump. Low face velocity at filters and coils ($10 K) Fan installation specified.	VAV supply, mechanical exhaust through space heating heat pump. Low face velocity at filters and coils ($10K) Fan installation specified.
Heating	Electric resistance heating in fan coils and at perimeter (250 kW) ($10K)	Electric heat pump from exhaust air (to maintain high efficiency) (130 kW) ($50K)	Electric heat pump from exhaust air (to maintain high efficiency) (110kW) ($40K)
Cooling	Low-cost rooftop unit, air cooled (350kW, $112K) Chilled water circulation with fan coils.	Built-up water cooled chiller (200 kW, $77K) with cooling tower and oversized heat exchangers ($38K) Full fresh air economizer ($5K) Efficiency measured during commissioning. ($10K)	Built-up water cooled chiller (150kW, $58K) with cooling tower, EHD heat exchangers, liquid pressure amplifier ($53K) and first stage (indirect) evaporative cooler. ($25K) Economizer with enthalpy control. ($8K) Adaptive controls ($15K) Efficiency measured during commissioning. ($10K)
Lighting	Low-cost fluorescent or incandescent with tungsten halogens (20+ W/m^2). Light circuits switched at random. (800 luminaires @ $375 = $300K)	Fluorescent with imaging reflectors, electronic ballasts and controls; halogens only where justified. (8 W/m^2). Light circuits parallel to windows to allow daylight switching. (450 luminaires @ $535 = $240K)	Fluorescent with imaging reflectors, electronic dimming ballasts and controls; halogens only where justified. (6 W/m^2). Light circuits parallel to windows to allow automatic daylight switching. (400 luminaires @$ 575 = $230K)

The predicted energy performance of these buildings are shown in Table 2, along with their annualised capital, energy, and total costs. The annualised capital cost assumed the capital for the building was raised on a 10 yr loan at 10%/yr interest.

Table 2 - Typical energy use and costs for 4,000 m^2, eight storey office buildings in Table 1

	Standard design	Least-cost design	Long-term least-cost
Extra cost	$422,000	$533,000	$564,000
Annual energy use	1,100,000 kWh/y (280kWh/m^2 yr)	320,000 kWh/y (80 kWh/m^2 yr)	250,000 kWh/y (60 kWh/m^2 yr)
Extra mortgage	$70,000/y	$78,000/y	$95,000/y
Energy costs	$110,000/y	$32,000/y	$25,000/y
Total annual cost	$180,000/y	$110,000/y	$120,000/y

In this case, the least-cost building had an additional capital cost above the standard design, as it included several features to reduce energy costs even further, to the least-cost point.

Case Studies

The Nelson (NZ) library is a local example of optimal design. For an extra cost of about $24,000 of natural ventilation and energy system design, the $55,000 cost of a standard air-conditioning system was avoided, as well as the operating and environmental costs of chat system. And the library is a much more attractive and better utilised than it would have been otherwise.

Portland General Electric company in Oregon, USA, reported five case studies of optimal design. All the buildings showed lower energy costs (averaging about 40% less than they would have been otherwise). Two of the five showed lower capital costs (and of the others: one was a first attempt, another a retrofit with limited chances for integration, and the third a cold-climate building with no chiller that could be reduced).

The costs and savings resulting from these case studies are shown in Figure 3. As shown, the worst-case (no chiller) resulted in a four-year simple payback, and the others were much better.

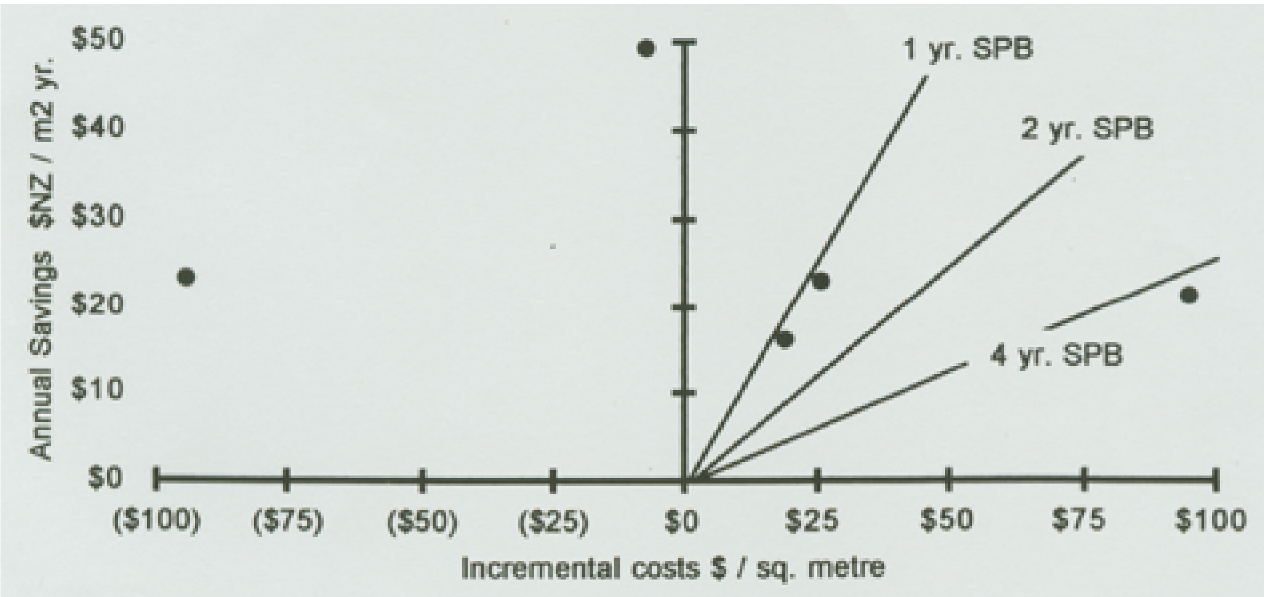

Figure 3 - Costs and benefits of Design Assistance, from PGE Case Studies

Commercial office buildings like these have been shown to increase productivity, by any measurable standard, by up to 15%. When the value of this improved productivity has been costed, it is typically ten times the value of the energy savings. (A detailed summary of the studies in this field is given in the recent book "Lean and Clean Management"[1].)

Important technologies

Window technology is one area where New Zealand can improve significantly. Because double glazing is currently uncommon, its costs are higher than will be the case when economies of mass production can be attained. Double glazing is the platform necessary to achieve improved windows. All the other technologies build on this.

The following graph shows the current (1996) costs of different, comparable window units in the United States, as a function of their R-value.[2] The units are all 900 x 1500 mm casement windows with wood frames, except the triple glazed window, which has a vinyl frame.

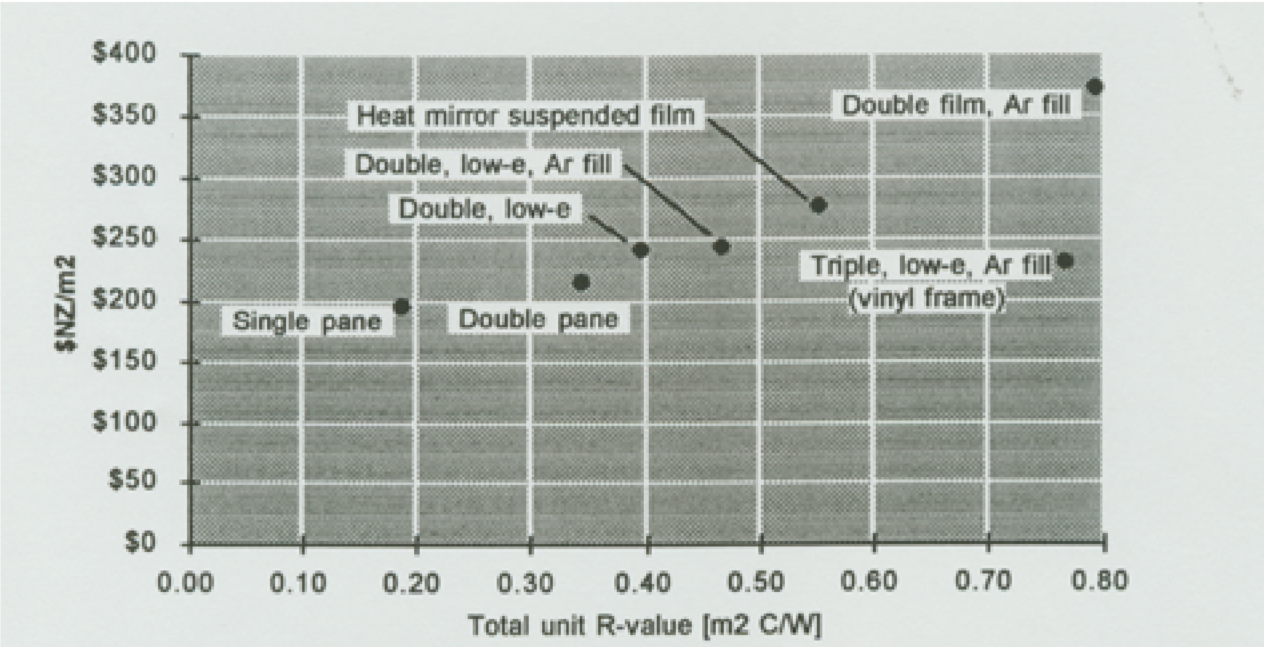

Figure 4 - Window costs as a function of R-value

As can be seen, the extra costs for double and other improved glazings are relatively low, compared to single glazing.

Domestic Design

An exercise where the requirements of least-cost energy efficient houses were specified (similar to that shown in Table 1 for commercial buildings) has been done for domestic houses. The specifications and costs for 110 m2 single-storey houses are shown in Table 3.

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1 Romm, Joseph }., "Lean and Clean Management - How to Boost Profits and Productivity by Reducing Pollution", Kodansha International Books, New York, 1994.

2 from Houghton, D. et. al., Space Heating Technology Atlas, ESOURCE. Boulder, CO USA, 1996 . Figure 5-46, converted as $1 NZ = $0.70 US, information available at www.esource.com

Table 3 - Typical and lease-cost energy efficient house specifications and costs

Component	**Standard design**	**Least-cost design**	**Long-term least-cost**
Walls (66 m2)	Timber framed, 100 mm studs. Insulated with 75 mm fibreglass batts (R 1.5) ($500)	100 mm studs, with 150 mm compressed batts (R 2.5) ($1000)	150 mm studs, with compressed batts or sprayed loosefill (R3.5) ($1,300)
Roof (110m2)	Timber framed, 150 mm joists. Insulated with 100 mm loosefill (R 2) ($400) or batts	Timber framed, 150 mm joists. Insulated with 200 mm loosefill (R4) ($800) or batts	Timber framed, 150 mm joists. Insulated with 300 mm loosefill (R6) ($1,200) or batts
Floor (110m2)	Timber framed, 200 mm joists, insulated with a single layer of foil (R 1) ($200)	Joist bottoms sealed, plus a single layer of foil (R 2) ($400)	Joist bottoms sealed, plus 200 mm bulk insulation (R 4) ($1000)
Windows (40 m2)	Single glazed, no restriction on size, placement, quality.	Double glazed, everywhere south of Auckland. ($4,000)	Triple glazed, argon filled, low-e coating. ($5,000)
Hot water supply	Normally electric resistance, temperature set by plumber.	Solar or heat pump water heater, sized for 70% of load, electric resistance backup. User-adjustable thermostat. ($3,000)	Solar or heat pump water heater, sized for 90% of load, electric resistance backup. User-adjustable thermostat. ($5,000)
Hot water storage	Cylinder insulated with 25 mm polyurethane foam (Watermark B grade)	Watermark A grade cylinder with 50 mm fibreglass insulation blanket. ($150)	Watermark A grade cylinder with 100 mm fibreglass insulation blanket. ($200)
Hot water use	Low pressure (header tank or pressure reducing valve), no pipe insulation.	Mains pressure with pipe insulation on hot water supply pipes, efficient showerhead. ($50)	Mains pressure with pipe insulation, efficient showerhead, ultrasonic tap sets and "Hot Water Saver®". ($500)
Heating system	Power points available for portable electric heaters.	Power points and timer/thermostats provided for portable electric heaters. ($50)	High efficiency heat pump with timer and thermostat. ($3,500)

The simulated energy performance of these houses in a Wellington climate, and total and annual costs, are shown in Table 4. These simulations assumed that the house was to be heated to 20°C during the day (8 AM - 11 PM), and a minimum of 16°C at night.

These are the temperatures necessary to maintain comfort during the day and avoid condensation on walls and ceilings at night. Condensation on walls and ceilings is believed to be a main cause of mould and respirable spores, and contributes to the dust mites problem, all of which have been linked to asthma and adverse health effects from houses.

Although tradition and cultural reasons preclude most New Zealanders from heating their houses to these levels, it is believed that when they become aware of the consequences, hearing for comfort and health will become standard.

Table 4 - Costs and savings from least-cost domestic houses in Wellington

	Standard design	**Least-cost design**	**Long-term least-cost**
Extra cost	$1,100	$9,450	$17,700
Annual energy use	10,000 kWh/y heating 4,000 kWh/y water heating 2,000 kWh/y other.	4,500 kWh/y heating 700 kWh/y water heating 2,000 kWh/y other.	800 kWh/y heating 400 kWh/y water heating 1,000 kWh/y other.
Extra mortgage	$100/y	$850/y	$1,600/y
Energy costs	$1,600/y	$720/y	$220/y
Total annual cost	**$1,700/y**	**$1,570/y**	**$1,820/y**

As can be seen, the least-cost design has an annual energy use about 60% lower than the standard house. Although its initial cost is about $10,000 higher than standard (mostly for the double glazing and solar water heating), its total annual costs are slightly lower.

The "Long-term least-cost" house has higher costs than either of the others at today's energy and efficiency technology prices, but this should become more cost effective as the price of energy rises and efficiency drops.

In North America, the National Association of Homebuilders Research Foundation has published a series of books on Optimal Value Engineering for houses[3], listing several hundred methods of reducing housing costs without compromising quality.

Conclusion

If optimal design is so valuable, why isn't it commonly done?

Unfortunately at present, design is treated as a commodity, and chosen on lowest cost. If energy efficiency is considered at all, it is late in the game, after most of the best opportunities have been foreclosed by the design.

Optimised design, using techniques that are presently available in New Zealand, allows construction of better buildings, which are much more occupant-friendly, much more environmentally-friendly, with much lower operating costs, and often lower capital costs.

In Europe, there are a number of companies that offer energy efficient, optimised design assistance services at very low cost, with incentives based on the reduced capital costs they deliver. In time, as New Zealand's design and construction industries become more sophisticated, these practices will become common here as well.

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3 These include "Reducing Home Building Costs with OVE Design and Construction", "Building Affordable Homes - A Cost Savings Guide for Builder/Developers", and "The Affordable Housing Demonstration - Three Case Studies", all from NAHB/RF and the U.S. Department of Housing and Urban Development in Washington D.C., USA.