ENERGY EFFICIENCY – ITS POTENTIAL: SOME PERSPECTIVES AND EXPERIENCES

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Much of the material in this paper may seem obvious to those experienced in the energy efficiency area. However, it seemed worthwhile to prepare a summary of a number of the important issues, so that the workshop can progress to consider practical paths forward.

Some Misconceptions about Energy Efficiency

There's not a lot of potential

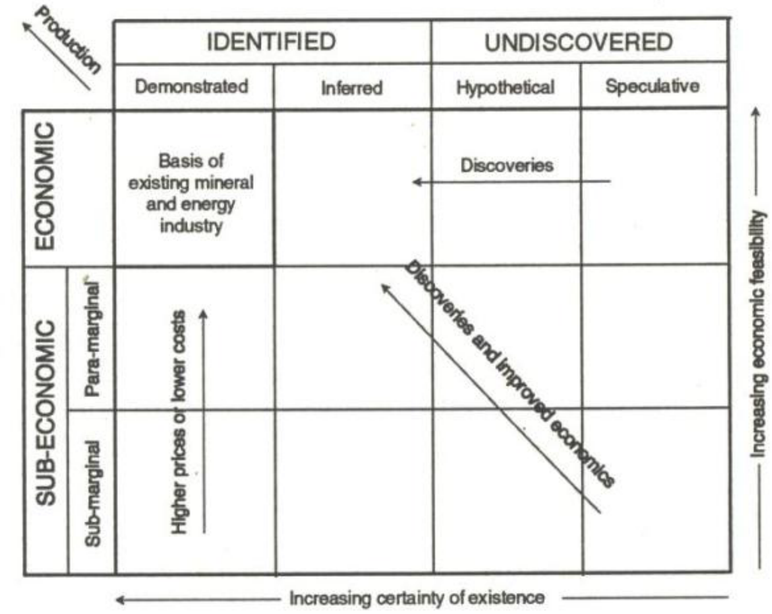
Many practical projects find energy savings of 5-15%, and may be used to support the argument that business is already close to optimum efficiency, so there is, logically little additional energy efficiency potential to be captured.

However, in the past, the same has been said about the world's oil supplies many times. Yet more resources have been found. Why is this? It's because the oil industry has traditionally not been particularly interested in proving up resources beyond its needs for the next decade or so. A useful way of looking at oil resources is that developed by the geologist McKelvey – the McKelvey Box, as shown in Figure 1. McKelvey recognised that, for any mineral resource, there is an ultimate limit to the resource, as defined by the outer boundary of the box. But within that total resource, there are categories of resources. The mining industry concentrates on the resource that is well-defined and can be extracted profitably. Other resources that could be extracted profitably could well exist, but they have little incentive to find them until they need them.

The McKelvey box also highlights how additional resources can become available. They can be discovered by appropriate exploration activity. Alternatively, their extraction can become cheaper or the price can increase, so that more expensive resources can be extracted profitably. Combinations of these options can occur. The McKelvey box reflects real experience with oil. An interesting question is whether conventional oil resources are reaching their limits, as many experts now take the view that world oil production will peak within the next 20 years.

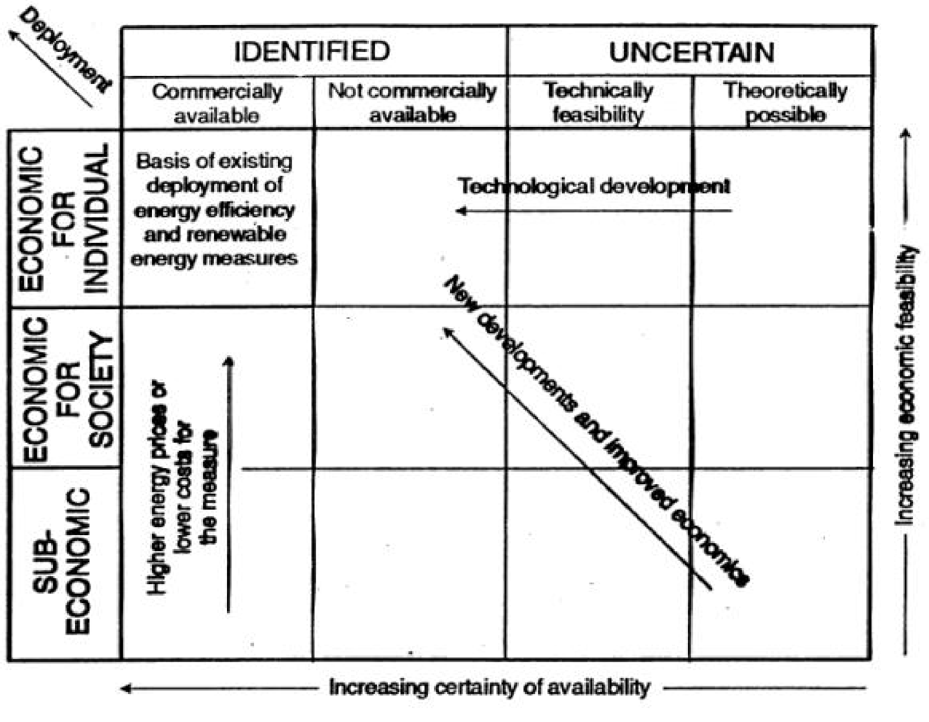
The McKelvey approach provides a useful model for considering energy efficiency resources, as shown in Figure 2, from Pears and Versluis (1993). Just as for oil, the identified resource that can be profitably captured by individuals in the short term is a small proportion of the total resource. The size of the resource can be increased by exploration – in this case research and technology development that moves solutions closer to the limits imposed by the laws of physics and chemistry, and social/cultural factors. The sub-economic resources can be captured either by applying societal economic criteria (eg internalising external costs of energy use and adopting 'rational' societal discount rates) or by driving costs down through capturing economies of scale, technology development and behavioural change.

Figure 1. The McKelvey Box for mineral resources (from Pears and Versluis 1993)



This model is consistent with experience of energy efficiency. For example, much of the difference between the large energy savings potential claimed by some energy efficiency experts such as ‘factor 4’ and those who claim small savings can be explained. Those who identify small savings typically look at existing or close to commercial technologies applied in limited circumstances under tough financial criteria, while those claiming large savings use low discount rates, propose solutions that are closer to the scientific limits and expect technological improvement and capture of economies of scale.

Figure 2. Energy efficiency potential using the McKelvey model (Pears and Versluis, 1993)



Confusion between 'economic' energy efficiency and 'functional' energy efficiency

Most gross studies of energy efficiency are based on measurement of energy use (or greenhouse gas emissions) per unit of economic activity, which is often described as the energy intensity of an economy or industry sector. Improving efficiency means reducing the energy intensity. Many studies by energy experts look at a different factor – functional energy efficiency or intensity. Functional energy intensity is the energy used per unit of delivery of a useful service. The relationship between the two indicators is:

$$\text{Functional energy intensity (energy/unit of service)} = \frac{\text{Energy use}}{\text{Unit GDP}} \times \frac{\text{GDP}}{\text{Unit of service}}$$

OR, stated another way;

$$\text{Economic energy intensity (energy/unit of GDP)} = \frac{\dfrac{\text{Energy use}}{\text{Unit of service}}}{\dfrac{\text{GDP}}{\text{Unit of service}}}$$

This relationship explains to a great extent how economic analysts can often see little change in 'energy intensity' while engineers claim to have delivered substantial improvements. They are talking about two different things! One reality of economic development is that the real cost of many goods and services has declined substantially. Since the contribution to GDP (often called Value Added) of production and sale of a given product is typically a fairly stable percentage of the price, the GDP per unit of service has typically declined.

From the equations above, it can be seen that if both the energy use per unit of service and GDP per unit of service decline, the two changes can cancel each other out, leaving the economic energy intensity unchanged. So the economist's scepticism of the engineer is confirmed while the engineer's frustration with the economist is reinforced. In reality, both are right – within different frameworks. This issue is discussed in more detail in Pears (1998).

Rebound effects will absorb most of the savings anyway

In broad terms, there are two dimensions to the 'rebound' effect:

- Technological/cultural rebound: as a result of application of the energy efficient technology, the level of service provided increases: this may result from one or both of an increase in technological capacity to deliver service (eg a water-saving showerhead means you can shower longer before running out of hot water) and a change in affordability of using energy (heating my home is cheaper, so I will heat to a higher temperature). At the extreme, this can lead to a situation where additional investment in more energy-intensive equipment occurs because of the increased technological capability. For example, the owner of a space-heated home may find that, when it is insulated, the space heater can heat most of the home, so (s)he may then invest in a central heating unit in the (probably correct) belief that it will not cost too much more to run and the house will be very comfortable. Another example is where introduction of LCD flat panel monitors leads users to specify larger screen size and/or multiple screens.

- Economic rebound: if saving energy saves money (after the cost of the measure has been repaid), then that money will flow through the economy, which may lead to additional energy use.

Technological/cultural rebound

Technological/cultural rebound is a complex phenomenon. Often the energy saving action is ‘blamed’ for changes that simply reflect underlying trends anyway. For example, each generation of new computers since the desktop computer became available has included larger screens, and multiple screens have begun to be adopted as new software has supported this feature. In that sense, the performance of the LCD screen should be judged against the existing trend, not the product it replaced. Similarly, there are strong trends towards whole house, all year comfort conditioning of houses. With showers, trends towards multiple bathrooms and smaller households have been leading to installation of larger capacity hot water services (and ‘continuous flow’ units) that are less likely to run out of hot water when people have long showers, regardless of energy efficiency strategies. Base demand for an energy service can also be influenced by cultural values (for example, in times of drought, people take shorter showers) and other unrelated factors, such as trends in hair length and introduction of combined shampoo/conditioner products.

So, when considering this form of rebound effect, it is more appropriate to look at the issue as an outcome of cultural values (which are amenable to change via education and information programs) and evolution of demand for services that involve energy use. In developing scenarios for the future, it is appropriate to assume that people will seek higher levels of comfort and amenity, but these trends have upper limits. For example, house size is constrained by many factors, while the length of a shower is constrained by the need to go to work or the tendency for skin to shrivel up.

Economic rebound

The term economic rebound effect is really only one side of the coin. The reality here is that the overall energy outcome depends on the energy intensity of the activity that is reduced and saves money, relative to the energy intensities of the activities on which the saved money is spent. A number of outcomes are possible:

- If the money saved flows through the economy and is allocated to more energy intensive activity than that avoided, total energy consumption increases. This is a critical issue in some economic models. As an extreme example, if a household energy consumer saves a dollar on energy and uses this to buy an ingot of aluminium (about the most energy intensive thing it’s possible to do) then the energy consequences are significant. The householder’s dollar saving is the outcome of saving 7 kilowatt-hours of electricity. However, spending a dollar on aluminium involves allocating around 30 cents of that dollar to electricity use, but at a price of about 3 cents/kilowatt-hour – an increase in energy use in the aluminium industry of 10 kilowatt-hours would occur. So the net outcome is an *increase* in energy consumption of 3 kWh, a very significant rebound effect.
- If the money saved is used to buy more energy-consuming equipment (for example, buying an extra heater), then direct energy use will increase but, since only a proportion of the purchase and ongoing costs of the new activity are covered by the energy saving, the household’s expenditure on energy will increase at the expense of expenditure on

other activities, and energy use elsewhere in the economy driven by that household's expenditure will decline. Since energy consumers often buy energy-consuming equipment with little regard for its long-term energy costs, quite large rebound effects may occur. This option often includes an element of technological/cultural rebound, as discussed above, which may further increase the size of the rebound effect.

- If the full cycle (i.e. considering all flows through the economy) energy intensity of the activity on which the money saved through energy efficiency is spent is similar to the intensity of the energy supply sector, there will be a negligible rebound effect, because the same amount of energy is being used throughout the economy by the dollar, whether it is used to buy energy for the householder or for the alternative service.
- If the money saved is spent on a lower energy intensity activity (such as hiring a DVD or paying for cable TV), then there may actually be a savings *amplification* effect, as the level of indirect energy use in the economy will be reduced by the shift in expenditure, while the household will continue to use less energy due to the efficiency improvement.
- If the money saved is invested in other energy saving measures (for example, if the person is so happy with their high efficiency fridge that they use their savings to buy other energy efficient appliances when they would otherwise not have done so) then there is a larger amplification effect because they save even more. Further, it is likely that widespread behaviour of this kind will influence the behaviour of manufacturers who are more likely to improve the efficiency of their products and services in order to maintain market share. Since the energy cost of energy efficient appliances is usually similar to or less than that of inefficient appliances, and one is substituting for the other, there should be limited or beneficial indirect energy impacts.
- If the money saved is invested in infrastructure used to manufacture energy saving equipment or systems (for example, the person invests savings in an insulation company or a company that makes energy efficient products) then an even larger amplification effect occurs, because the manufacture and delivery of energy efficient products and services displaces inefficient ones.

The point of discussing these various possible outcomes of improving energy efficiency is to highlight the fact that they can vary from large rebound effects to large amplification effects. Policies, education and information can influence the outcome. For example, driving aggressive mandatory energy efficiency standards with quite long payback periods diverts money towards investment in energy efficiency and away from other economic activity, reducing the rebound effect. Through changing the behaviour of product and service suppliers, it can also transform the outcome into an amplification effect. Promoting investment in businesses that offer energy efficient products and services can build this sector of the economy, displacing businesses that deliver inefficient alternatives.

It is also important to recognise that economic models often incorporate past relationships between sectors so that they may overstate rebound effects. For example, if in recent history energy intensive activity has grown faster than the rest of the economy, then allocating money freed up by energy savings across the economy based on past experience will 'drive' more rapid growth of energy intensive industry in the modelling when there may be no other reason to expect such growth. This seems to be a significant factor in modelling the impacts of response to climate change on the Australian economy.

Energy efficiency is relatively expensive greenhouse abatement

Most people choose not to invest in energy efficiency measures with a simple payback period of more than a few years. Yet this is economically and environmentally irrational behaviour. Table 1 below shows that, in reality, investing in very long payback energy efficiency measures is actually cheaper per tonne of CO_2 avoided than most other options for emission reduction. In fact, investing in energy efficiency measures with simple payback periods of 12-15 years is equivalent to paying \$30 per tonne for CO_2 avoidance. We simply don't look at energy efficiency potential in the right way. Any organisation or individual that invests in carbon abatement measures that cost money before investing in all options for cheaper energy efficiency is failing to capture its best opportunities.

Table 1. Relative costs of actions to meet emission reduction targets for a business that normally achieves 15% pa rate of return on investment (Pears, 2000)

ACTION	COST/TONNE OF CO_2 AVOIDED OR STORED	COMMENTS
Buy 'credits' from tree plantations	\$5-\$30	Cost depends on many factors
Buy permits on market	\$7-\$50	Economic modelling shows a wide range of costs, depending on assumptions in the modelling
Buy *Green Power* or other zero emission renewable power at 3 c/ kWh premium	\$30 to \$40/tonne (Aust mainland ave - \$22/t if it replaces Victorian average electricity, which gives a bigger CO_2 saving per kWh)	Use of energy involving capture of methane that would otherwise have been released into the atmosphere may have a lower cost/tonne of CO_2 equiv avoided, as the benefits of removing very greenhouse-active methane from the atmosphere may be counted
Buy low emission electricity at 1 c/kWh extra cost – eg hypothetical small scale cogeneration	\$10 to \$15	Assumes electricity at 1.0 kg CO_2/kWh replaced by electricity from cogeneration or combined cycle gas at 0.25 to 0.33 kg CO_2/kWh. If low emission energy purchased at same cost as BAU energy, cost/t CO_2 avoided is zero
Buy low emission electricity at 0.5c/kWh less – eg cogeneration	-\$3 to -\$\$5	As for above
Invest in energy efficiency measure with 1 year payback	-\$32 (yes, a negative cost!)	Assumes 10 year life of measure, 8 c/kWh and 1.0 kg CO_2/kWh for BAU electricity, and 15% pa discount rate to reflect 15% IRR threshold
Invest in energy efficiency measure with 5 year payback	-\$4.50	Assumes 15 year life, 8 c/kWh and 1.0 kg CO_2/kWh for BAU electricity, and 15% pa discount rate to reflect 15% IRR threshold
Invest in energy efficiency measure with 7 year payback	\$6.15	As above

We must also keep in mind that the cost of energy efficiency improvement declines over time due to factors that include:

- Decisions made by participants in the supply chain regarding the profit margins they apply: typically where a feature is seen to be of high value, or only likely to appeal to a small niche market, margins will be high. This is partly to reflect higher costs, but also reflects the aim of making more profit from premium product. As energy efficiency becomes more normal, this premium reduces.

- Many efficiency features ‘piggy back’ other seemingly unrelated developments such as sensors, computers, power electronics and improved materials. For example, the same sensor can be used for security systems and for energy efficient lighting, so synergies and economies of scale can be captured for energy efficiency.
- The economics of scale mean that, typically the cost of new products declines by 20-30% for each cumulative doubling in the number produced: this is a powerful factor early in the evolution of new products, and we have seen it recently with LCD monitors.
- There is a ‘normality’ effect, so that when a product becomes the standard choice, the number and complexity of transactions associated with its use decline, and the supply chain costs fall dramatically. Since supply chain costs and margins are typically around three-quarters of the retail price of a product, this can have a very powerful effect on price. For example, it is commonly noted that double glazed windows are cheaper in some regions than single glazed ones, even though there is a slightly higher material cost. The reason for this is that once double glazed windows become standard, making a single glazed unit is a ‘special task’ that requires non-standard activities that add to costs.

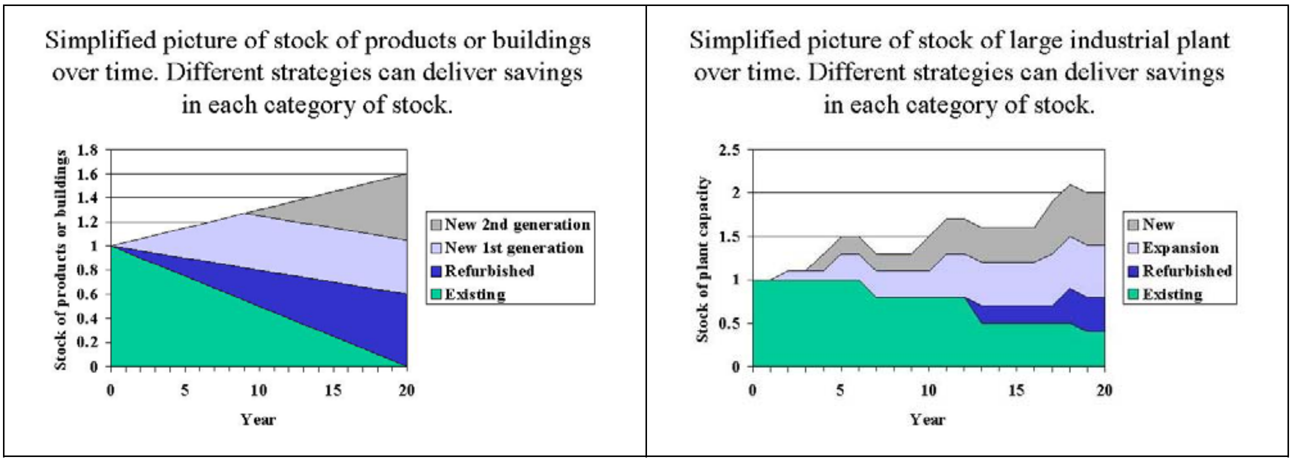
Only a small amount of energy efficiency can be captured each year

The stock of buildings, industrial plant and equipment turns over relatively slowly. So if energy efficiency programs focus only on small savings in new facilities and equipment, the potential for energy efficiency each year is small. But that is not the real situation.

In reality:

- savings potential for new facilities and equipment is large, not small: it is a question of policy, technology development and community values as to whether this large potential is captured
- programs can target existing facilities and refurbishments, which provide substantial opportunities for savings in existing stock
- significant savings can be delivered in existing stock by programs that fix problems and modify behaviour

Figure 3. Indicative graphs of the shares of stock of existing, refurbished and new equipment or plant over time



Simplified picture of stock of products or buildings over time. Different strategies can deliver savings in each category of stock.

Simplified picture of stock of large industrial plant over time. Different strategies can deliver savings in each category of stock.

The graphs in Figure 3 highlight the reality that, for long-lasting assets such as industrial plant, rapid improvement in overall energy efficiency requires a mix of actions that improve the performance of existing plant while also ensuring that new plant and major refurbishments achieve maximum efficiency. Otherwise, total energy consumption will continue to grow. For equipment with a more rapid turnover, the performance of existing equipment may not be so important. However, it is surprising how long many old items of equipment actually remain in use (often while their efficiency deteriorates), so there is a case for strategies that encourage their retirement – as long as new alternatives are close to long-term optimum efficiency.

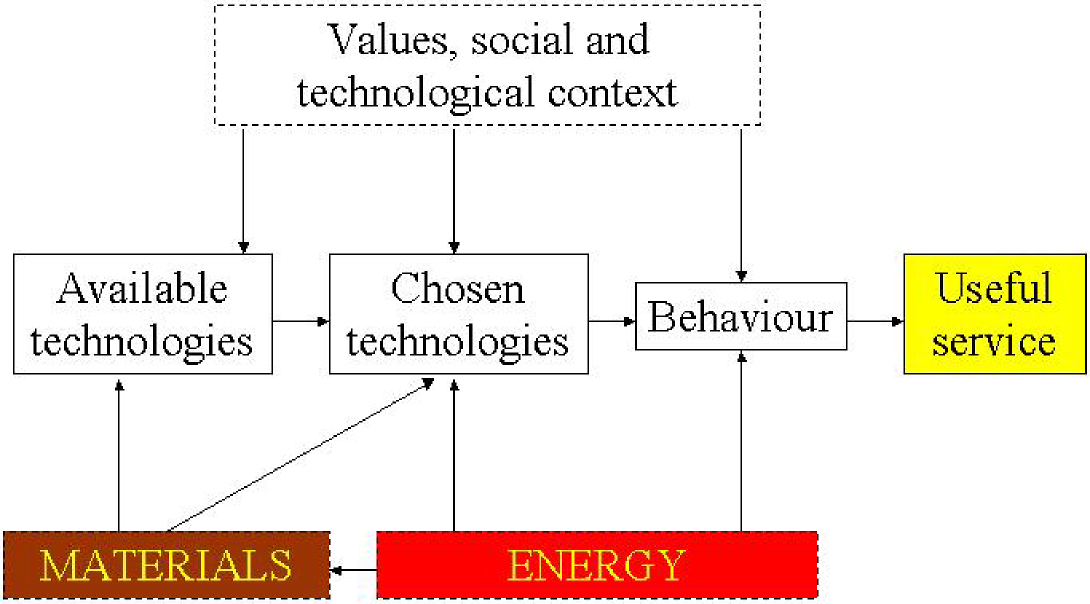
Identifying potential for efficiency improvement in practice

Services thinking

Energy is not used for its own sake. It is one input to a system that produces an output that is considered useful or valuable within a cultural context, as shown in Figure 4.

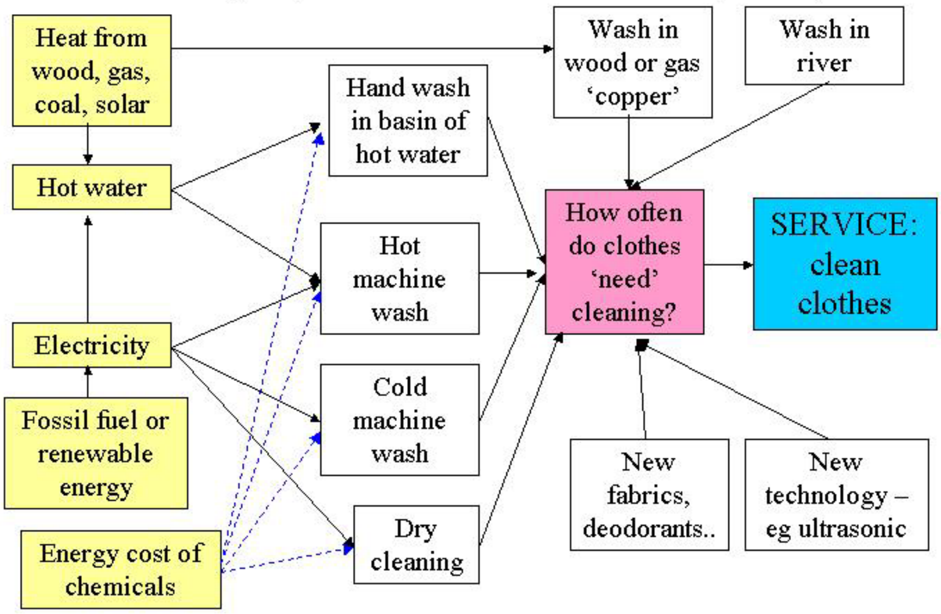
Choices are made in the selection of technologies and energy sources, and the interpretation of the nature of the useful service. Figure 5 shows just one example of what might be considered to be a simple service – that of providing clean clothes. This highlights the many choices that are available, each with its own unique energy and environmental impacts.

Figure 4. A model of the inputs to useful services



Taking a service-based approach helps to clarify the nature of the essential services that require energy inputs, and facilitates consideration of alternative ways of achieving the required outcome. This can lead to radically different energy requirements, usually involving savings. The correct definition of a service requirement is an important step towards identification of the potential for energy efficiency improvement, as it facilitates consideration of options that lie ‘outside the square’.

Figure 5. An example of the supply of an energy service, the provision of clean clothes, showing the range of choices available (adapted from Pears and Versluis, 1993)



Systems thinking

Most energy efficiency projects deal with only some elements of an energy-consuming system, not the whole system. That is one reason why they fail to capture the full savings potential. Consider a simplified example of an electric motor driving a pump that circulates a liquid around an industrial site. This system includes the following elements:

- electric motor (sizing and efficiency rating)
- motor controls (switching, speed or torque control)
- motor drive system (belts, gearboxes etc)
- pump
- pipework
- demand for the fluid (or in many cases the heat or coolth it carries)

The efficiencies of these elements interact in complex ways that, ideally, should be modelled. But consider a simplistic situation where the overall efficiency of the motor is improved by 10% (by a combination of appropriate sizing and selection of a high efficiency model). Then overall energy efficiency is improved by 10%. But if every element in the chain is improved in efficiency by 10%, then the overall level of energy use is:

0.9 x 0.9 x 0.9 x 0.9 x 0.9 x 0.9 = 0.53. That is 47% savings are achieved.

In most situations, such a systems perspective is rarely applied, because responsibilities for different elements of the system are allocated to different groups, so the savings captured are small. Indeed, individual agents may not be aware of the potential for savings in other parts of the chain – or may prefer them not to happen. For example, does a manufacturer of aluminium from virgin material really want to encourage higher rates of aluminium recycling? Further, if a systems approach is applied, it is possible to re-allocate capital costs from one area to another, for example savings from downsizing motors and other components and using shorter pipes may offset the cost of installing larger diameter pipes (for reduced flow resistance) and improved controls. But this may be seen as a threat by individual agents: if the services engineer for a building is paid a percentage of the capital cost of the air-conditioning system, why would he recommend improvements in the building envelope that would reduce the cost of the air-conditioning system?

Identifying waste

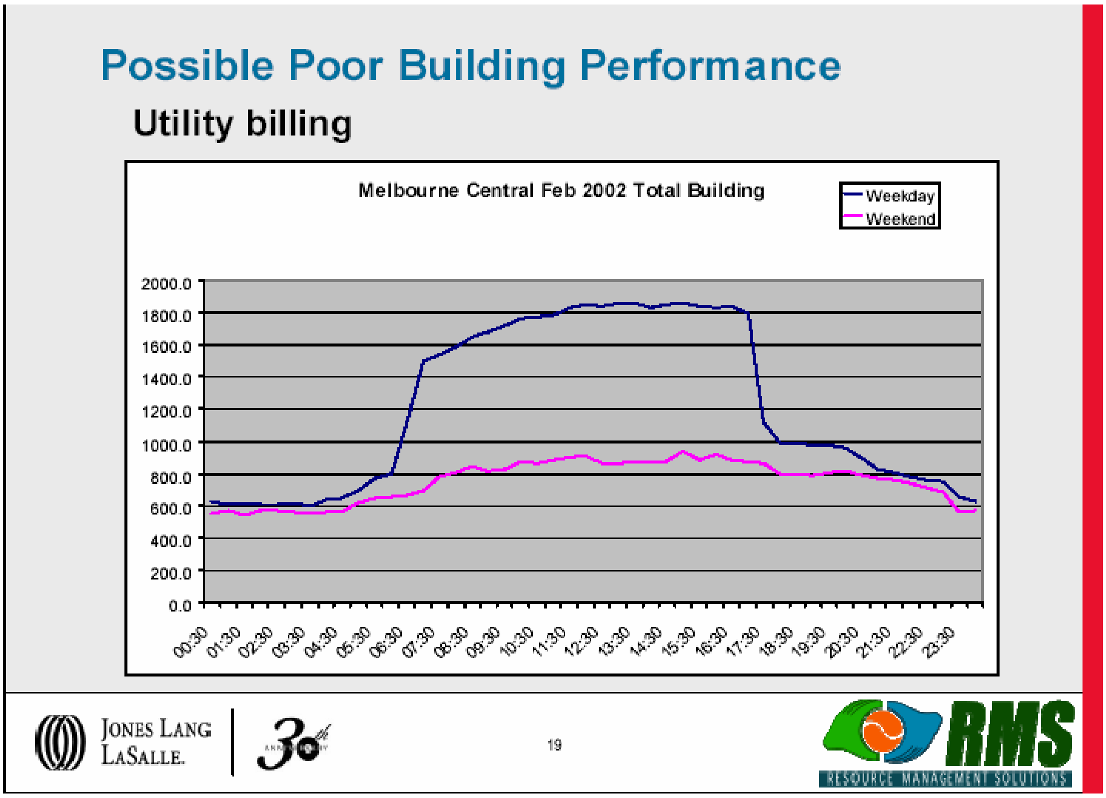
At most sites (from homes to large industrial plants), there is very limited measurement and monitoring of energy use at the process level. Further, rarely are there properly specified benchmarks against which performance can be evaluated. So rarely do the plant operators know what is possible.

An example of a situation where monitoring and benchmarking at the process level could save large amounts of energy was a situation in an oil refinery studied as part of the Energy Efficiency Best Practice program. Two pumps were installed in parallel to circulate fluid through a pipe system. In theory, the pumps were identical, although one motor was a high efficiency model while the other was a standard model. During plant operation, the two pumps would normally be alternated so that each runs for half of the time. When energy consumption was measured, it was found that the pump with the less efficient motor used 84% more energy than the other while doing the same task. The difference in motor efficiency could account for less than a third of this difference in energy use, so other factors were responsible for the bulk of the difference. It was not possible within the project to stop the equipment and inspect it to find the actual reason(s) for the difference, but this may be accounted for by factors such as a damaged or worn pump impellor, obstructions in the pipework around the pump, such as a poorly fitted gasket or surface roughness, poor motor shaft alignment, and so on. While ideally the problem should be rectified (with savings potential of over 40% because the inefficient motor/pump is used for half of the operating time), most of these savings could be captured simply by running the efficient motor/pump most of the time, using the inefficient one as an emergency back-up.

In office buildings in Australia, energy consumption often far exceeds the levels expected on the basis of computer simulation. Thorough inspection and benchmarking usually leads to identification of the reasons for this, and the problems can be rectified. Often the problems are related to relatively minor issues such as inappropriately operating controls, excessive reheat, excessive air leakage into the building, and so on. A useful case study is that of the Melbourne Central office building, a large office building constructed in the early 1990s. The in-house engineer considered this building to be quite energy efficient, and was very disappointed when an assessment of its energy usage by the NSW Sustainable Energy Development Authority for its Australian Building Greenhouse Rating Scheme rated it at only 2-stars, instead of the expected 3.5 to 4 stars. Two independent audits failed to identify significant problems. However, analysis of the electricity demand profile of the building showed it was using surprisingly large amounts of energy outside working hours, as shown in Figure 6. The engineering investigations had been conducted during working hours. Investigations outside working hours found controls malfunctioning, as well as some diversion of the central chilled water system for use in cooling tenants' computer centres. The building managers are now very happy. They are making more money and they have commissioned repairs to achieve the expected star rating.

Numerous experiences demonstrate that designers and engineers generally assume equipment is working properly when it often is not. Lack of measurement, monitoring and benchmarking means that problems can remain undiagnosed for long periods, wasting energy and money, and contributing towards risk of failures and increased maintenance costs.

Figure 6. Daily load profiles for Melbourne Central, a large office building – note that weekend energy consumption is almost half of weekday daytime demand, even though most of the building is unoccupied. (From Ostoja, 2003)



Possible Poor Building Performance

Utility billing

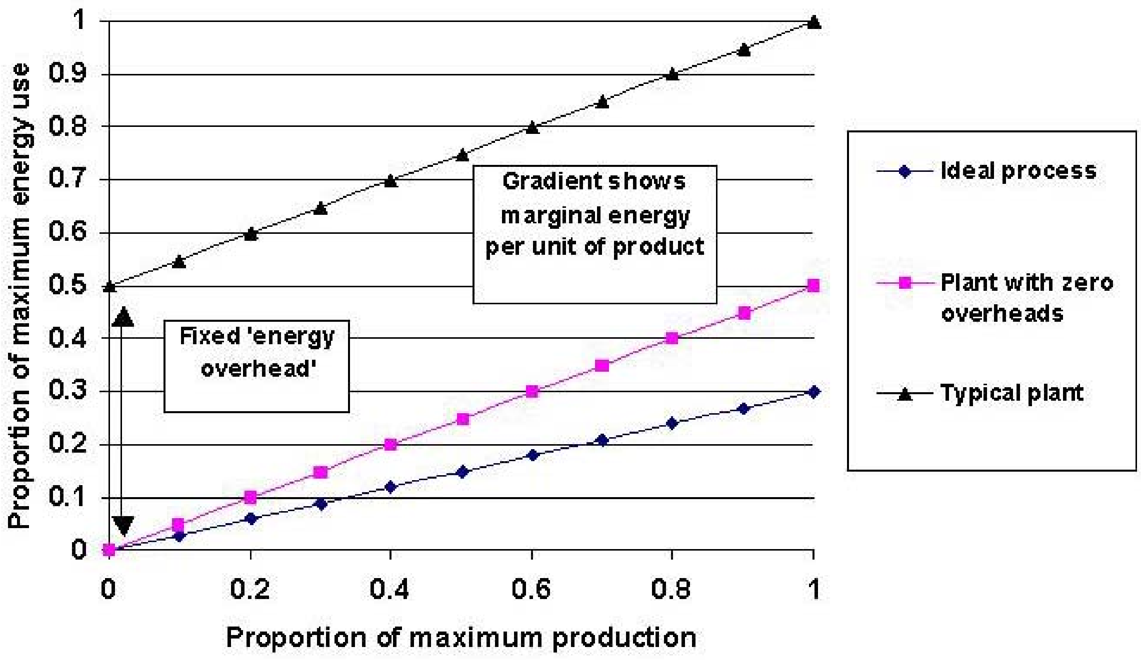
Target the right things

In most systems, from household appliances to office buildings to industrial sites, the nature of energy use can be characterised as shown in Figure 7. In an ideal process, no energy is used when the system is not doing anything useful. The gradient of the graph should reflect the ideal amount of energy used to run the process. In practice, most plant and equipment has surprisingly high fixed energy overheads (which could be described as standby energy use). The gradient of the typical process is steeper than the ideal graph, reflecting the inefficiencies within the process.

Experience with systems ranging from large industrial plants to retail stores to homes shows similar characteristics. An effective strategy looks at both the fixed energy overheads and the system's marginal efficiency. Often only one or the other is addressed. This is important where there is debate about rebound effects or criticism of overly optimistic estimates of savings potential. For example, if fixed energy overheads comprise half of total consumption, a measure that improves marginal energy efficiency by half will only deliver 25% overall savings. So the expected 50% energy savings are not seen when energy bills are received, and everyone will find something (or someone) to blame, while the credibility of energy efficiency in principle will be undermined. One situation where this occurs is in improving the thermal performance of a building envelope. If the heating system has significant fixed energy losses due to distribution losses (which is not unusual), halving the heating energy requirements of the building envelope may deliver much smaller measured overall savings than expected.

The message here is that energy consuming systems are not simple. Ideally, they should be modelled under a range of realistic operating conditions, so that appropriate priorities for savings measures can be set and reasonable estimates of energy savings from each measure can be made.

Figure 7. Energy use of a typical production system compared with one with zero energy overheads and the ideal process.



Delivering large savings

This section of the paper does not attempt to deal with issues related to policy and program development and implementation, innovation and barriers to energy efficiency. It looks at the processes that can be used to identify large savings and capture them in the appliance development process or at a site.

Understand the system and benchmark against what's possible

The first step towards achieving large energy savings is to understand the fundamentals of the process, clarify the essential services being provided, and clarify how the existing system compares with the ideal and the best practically achievable. Benchmarking against 'Best Practice' is a dangerous strategy: existing best practice is actually *best of a bad lot practice* because the reference cases typically were designed several years ago and the financial criteria used to evaluate investments in energy efficiency are likely to have been very stringent (less than a three year payback period is a typical threshold). Today we should be able to do much better.

It is often useful to develop a simple spreadsheet model of the system being evaluated. It is remarkable how useful this can be, as it forces the analyst to think about the interactive elements of the system, and to evaluate the existing solution. For example, when the author was working on the *EcoVend* drink vending machine project with RMIT University's Centre for Design (www.cfd.rmit.edu.au), it proved impossible to make a simple computer model give a level of energy consumption as poor as that measured on real existing drink vending machines. This led to careful study of the existing product, which revealed that there were a number of serious flaws in the design of existing products, including:

- The evaporator fan was very close to the rear wall of the cabinet so that it was moving less than a tenth as much air as it was meant to: it was operating under ‘stall’ conditions with the air it blew bouncing back onto the fan blades. In turn, this led to the evaporator icing up because the rate of airflow was far below the design requirement (further undermining efficiency). Inquiries of the maintenance staff unearthed the fact that replacement of worn fan bearings was a major maintenance problem – not surprising, really, as the fan was under extreme load from the blown air rebounding from the nearby cabinet wall. It seemed that the fan had been relocated so that an extra row of cans could be fitted into the cabinet without consideration of the implications
- Outlets for hot air leaving the condenser were quite small, so much of the cooling air actually flowed back to the fan inlet (as there was no barrier to this) and the condenser stewed in its own heat

The RMIT EcoVend prototype achieved an energy consumption of 4.3 kilowatt-hours per day, compared with over 10 kWh/day under the same conditions for a conventional drink vending machine of 1993. The Mandatory Minimum Energy Performance Standard now being considered by the Australian Government is 7.5 kWh/day. With technology improvements available today, it should be feasible to cut consumption to close to 2 kWh/day. Even then, the energy required to actually cool cans to drinking temperature would typically be less than 20% of total consumption.

Modelling of the interaction between the heating and cooling system, the refrigeration system and lighting in a supermarket for the EEBP program highlighted some interesting issues:

- Installation of high efficiency lighting in cool climates didn’t necessarily save much energy, because the building required heating all the time to compensate for the cold air spillage from the open refrigeration units, and the inefficient lights provided a useful source of radiant heat that had to be sourced from elsewhere when they were replaced!
- Energy use was extremely sensitive to the quantity of outdoor air leaking into the building, because each kilogram of water vapour that entered would undergo several phase changes: from vapour to liquid to ice, then defrosting back to liquid for removal: this process consumed up to 1 kilowatt-hour per litre of water vapour

A regression analysis of data from a sample of supermarkets broadly confirmed these findings: it showed that energy efficient lighting was not strongly linked to energy savings (in a cool climate) and that installation of an airlock (which significantly reduces air leakage) was associated with large energy savings. This analysis highlighted the importance of aggressive control of air leakage (through doors, loading bays, exhaust fans, small gaps in the building fabric, etc). It also highlighted the major significance of air spillage from open refrigeration equipment as a driver of overall energy use in a supermarket.

Run processes that cross cultural boundaries within the organisation and between industries

The main energy saving opportunities cross cultural boundaries within organisations, and often cross boundaries between organisations, industry sectors, market intermediaries and customers, so it is not surprising that most do not capture them.

The Energy Efficiency Best Practice program, run by the Australian Commonwealth Department of Industry Tourism and Resources until mid 2003, in which the author of this paper played a key role both during development and implementation, attempted to capture large savings in industry. The details of this program, and numerous case studies from projects pursued, are available at www.industry.gov.au/energybestpractice .

Key strategies used in this program included:

- Preparation of background papers that analysed situations in more fundamental ways and encouraged thinking 'outside the square'
- Use of cross-cultural teams facilitated by independent people
- Use of external specialists (often from outside the industry sector) to inject knowledge and credible alternative ways of seeing and doing things
- Engagement of senior management by highlighting the potential to address issues of broad organisational value beyond just reducing their energy bills, such as:
  - Positioning the organisation to avoid becoming a victim of energy markets
  - Strategic response to climate change issues
  - Improved productivity
  - Improved capital investment decisionmaking
  - Improved organisational culture through empowerment and communication

In many cases, this program captured large savings beyond those that had been captured by in-house staff and energy efficiency consultants. Why? Because it redefined the boundaries of the problems (and opportunities). It also challenged assumptions accepted by the staff.

The program highlighted a significant lack of understanding of the laws of physics among technical staff. It also highlighted a tendency by staff to assume systems worked as designed, instead of confirming it by measurement and monitoring. The sorts of things we found were:

- Large boiler feed water tanks that were uninsulated but sitting in the open air at 75C. Why? Staff had noted that when the plant wasn't running, the temperature of the water in these tanks fell quite slowly: it was therefore inferred that heat loss was not great. In reality this outcome was due to the very high thermal capacity of a large volume of water, and actual heat losses were hundreds of watts per square metre of surface area, and even more when it was windy or raining.
- At a plant that had a boiler designed for co-firing of timber waste and natural gas, our analysis showed that during co-firing the consumption of gas hardly changed and nor did the output of the boiler: inefficiencies created by the way the timber waste was loaded seemed to offset a significant proportion of the extra energy input!
- Kilometres of steam pipe in a large plant were uninsulated. Part of the problem was that the maintenance manager saw insulating the pipes as a cost to his department, but the benefit accrued to another department. And since the site ran a cogeneration system, it was also argued that reducing the steam load would reduce electricity output and cause the plant to have to import electricity from the grid, at what was believed to be a higher cost. We suggested that they should integrate their pipe insulation program with an electricity efficiency program, to maintain the load balance.
- An operator of a refrigeration plant seriously underestimated the impact of higher condenser temperatures on the efficiency of the plant: an external refrigeration specialist was able to clarify the issues.

- Many plants that operated for 50-80 hours per week had large boiler systems or refrigeration systems that could not be shut down and restarted reliably or quickly, so there was massive standby energy waste because they ran continuously (168 hours/week)
- Some facilities, for example wineries, had large amounts of high capital cost equipment that was fully utilised for very short periods of time: load management strategies offer both capital and energy savings
- Thermal bridging and air leakage were often major contributors to energy losses. For example, a bakery oven evaluated based on actual standby energy consumption had an effective average thermal resistance of R0.22. This compares with a typical insulation value in a house ceiling of R3. The unnecessary 8 kW of heat loss from this oven was a major contributor to the discomfort of staff in the kitchen. In turn, the uncomfortable working conditions are a key factor affecting the difficulty of attracting staff to this industry. The business is actually paying for the energy that undermines its ability to employ good people. To an energy efficiency specialist, this seems bizarre. But to most others it seems to be normal.

Analyse and present information in useful diagnostic forms

In this computerised age, most people are awash with data. But it is often the wrong data, and it is often not in a useful form. Some aspects of what is needed include:

- Benchmarking against the ideal, against other similar systems, against different times of day, and against different levels of activity
- Monitoring performance at a system and process level, so operators and engineers have the data they need to understand what is really happening and manage it
- Visually linking changes in energy use levels to the activities that cause them
- Providing a historical perspective
- Identifying parts of a site or specific processes where large energy losses are occurring
- Comparing costs and energy use, lifecycle costs, etc

The following Figures provide some examples of ways of presenting information that have been found to be useful to clients.

Figure 8. Breakdown of energy use by activity for a traditional drink vending machine when delivering 50 cans per day.

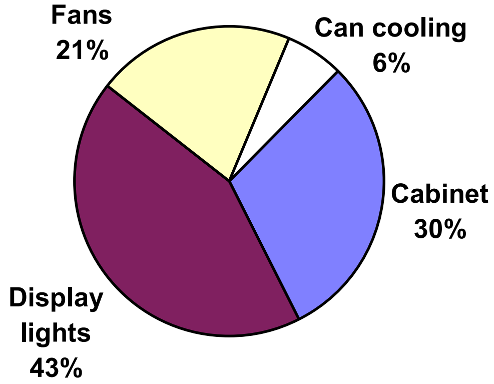


Figure 9. Lifecycle greenhouse impacts and costs of a traditional drink vending machine

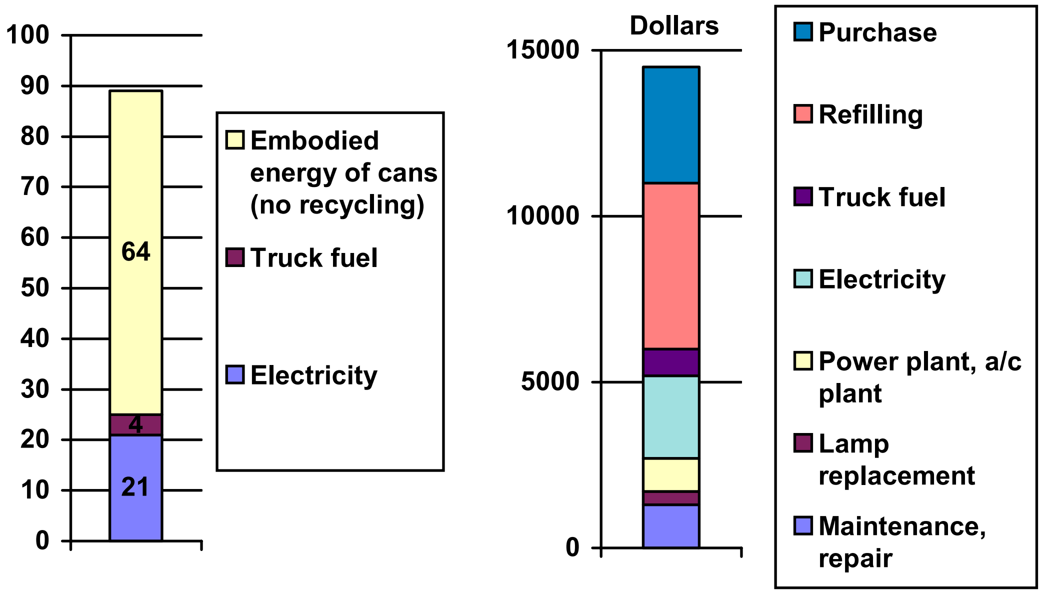


Figure 10. A building's actual energy use compared with its design target and best practice.

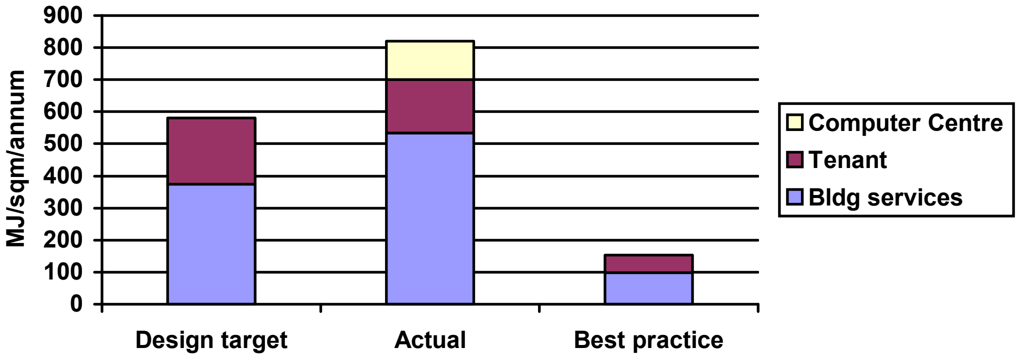
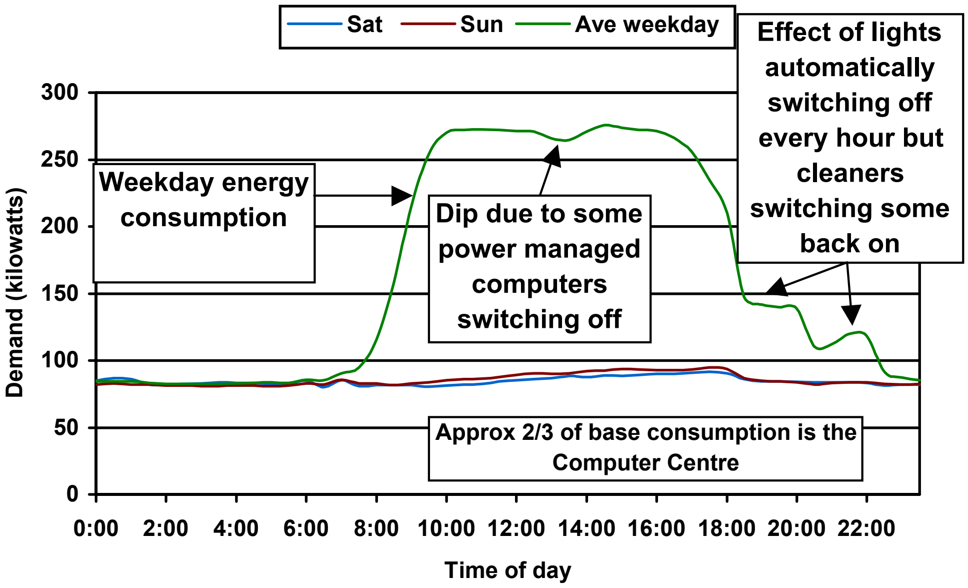


Figure 11. Presentation of electricity demand of an office tenancy with information on factors contributing to usage.



Of course, information is only effective if it is used as a basis for implementation of action. So appropriate organisational mechanisms that can act on the information are also critically important.

Conclusion

There are many misconceptions and confusions about the nature and potential of energy efficiency. And when it comes to delivering significant energy savings, there is still a lot to be learned about successful identification and capture of savings. Despite these challenges, aggressive pursuit of energy efficiency offers an exciting opportunity to reduce total energy costs and greenhouse gas emissions while improving quality of life and business productivity. But when many policy advisers cannot grasp the potential, when economic models include systematic biases against energy efficiency, and when powerful vested interest groups work hard to convince politicians and policy specialists that energy efficiency opportunities either do not exist or are very limited, it is very difficult to make progress.

References

Pears A and Versluis P (1993) *Scenarios for Alternative Energy in Western Australia* Report for Renewable Energy Advisory Council, Government of Western Australia, Perth

Pears A (1998) *Global Warming: Closing the Gap between Economic Modelling and Technology-based Analysis of Emissions Trends and Cost of Response Measures* Aust NZ Environmental Economics Conference Nov, Melbourne

Pears A (2000) *Using Emissions Trading to Create Incentives for Demand-side Management* paper presented at Sustainable Energy Industry Association National Conference, Melbourne Oct

Ostoja A (2003) *Existing Buildings: 360 Elizabeth Street, Melbourne* Australian Building Greenhouse Rating Second National Case Study Seminar, Sustainable Energy Development Authority, Sydney