TALES OF THE UNEXPECTED: the use of building performance modelling for regulatory activity in Australia

Author: Alan Pears
Sustainable Solutions Pty Ltd

This paper describes a number of issues which building modelling must take into account if it is! to he used as a tool in government policy making and regulatory frameworks. It points to, the importance of empirically verifying data inputs and model output to ensure credible results and demonstrates the importance of considering both envelope and plant characteristics, even for residential buildings. Capital costs and running cost are demonstrated to be equally important in policy making decisions.

Introduction

Victoria introduced basic residential building energy efficiency regulations in 1991, after more than fifteen years of debate. A comprehensive cost-benefit study has recently been conducted to underpin consideration of possible regulation in New South Wales (UNISEARCH, 1993). Attempts to utilise computer models to calculate benefits from energy efficiency regulation have raised questions and, sometimes, modelling results have not been perceived as credible by industry, energy suppliers or government.

The author played a central role in the development and implementation of the Victorian regulations, and has contributed to the NSW cost-benefit study. In this paper, many of the problems and issues related to the application of computer modelling to analysis for regulatory purposes, which have arisen in these processes, are discussed. Some paths forward are proposed.

To contact Sustainable Solutions:
Alan Pears and Peter Brotherton.

Phone: (03) 592 8581
Fax: (03) 593 1580

Address: 2/78 William Street,
Brighton VICTORIA 3186

Information Requirements for Regulation

The introduction of new regulations in most parts of Australia must now be preceded by extensive analysis that demonstrates net community benefits and identifies any specific groups who might experience adverse impacts. The magnitude of net community benefits is usually assessed in economic terms. Accurate calculation of costs and benefits is dependent on the availability of detailed numerical information regarding the impacts of the measures proposed for regulation.

The evaluation of costs and benefits of energy saving measures for regulations should be done from a number of perspectives: those of the occupant, the energy utility and society. Components of the costs evaluated from each of the above perspectives should include:

* capital investment
* operating costs
* impacts of revenue loss on utilities and tariffs
* externalities, including improved occupant comfort and health and environmental impacts.

To estimate the costs and benefits of energy efficiency measures which reduce heating and cooling energy use, regulators need to know:

* impacts on metered energy consumption on a fuel-by-fuel basis

* possible changes to specifications (and hence costs) of heating and cooling plant resulting from application of the measures

* impacts on utility load profiles during peak hours and days, and on a seasonal and annual basis

* changes in internal temperatures in living and sleeping zones of dwellings and working areas in commercial buildings.

To effectively address these issues requires, in addition to computer modelling capability, a detailed database of stocks of appliances, equipment and building characteristics, information on occupant behaviour, and an understanding of the appliance technologies used now and in the future. The model must also provide detailed output showing peak demand characteristics.

The failure in the past of building modelling studies to report this comprehensive information, and to validate it against real-world data can have a number of outcomes:

* significant costs and benefits from efficiency measures may be ignored, on the basis of the well known philosophy of "if you can't quantify it, set its value to zero";

* results of modelling may be ignored or undervalued, as industry groups, bureaucrats and politicians seize upon differences between surveys, anecdotal experience and modelling results to undermine the credibility of computer modelling when its outcomes are not compatible with vested interests.

Apart from the community costs of these outcomes, they work against the allocation of additional resources for modelling work and development of improved models. Thus, it is in the interests of building modellers to invest effort in improving the correlation of their models with survey data - or at least to explain any variance - and to ensure that they provide comprehensive information on metered energy savings and capital investment impacts.

Major Issues

Peak energy demand, capital and operating costs

The level of peak heating and cooling demand of a building determines capital investment requirements for energy suppliers and the building developer. Peak heating and cooling demand occur infrequently, and usually coincide with annual peak demand, which determines the system capacity requirements for energy suppliers.

The Victorian Gas and Fuel Corporation (1991a) estimates that domestic space heating will comprise about 43% of peak day demand by 1996. To satisfy this load, the Corporation is considering increased disconnections of large customers, underground storage and new sources of supply. All these options are costly.

Electricity utilities also incur large costs in satisfying peak demands. In Western Australia, peak demand on a hot summer day in 1989 (Pears and Brotherton, 1990) was approximately 400 Megawatts (33%) higher than on an average summer day, largely due to commercial cooling loads. Not only must additional generation plant (costing $500 to $2,000 per kilowatt of capacity) be established, but additional reserve plant, transmission and distribution infrastructure must also be installed. This can exceed a total of $2,000 per marginal kilowatt of demand, far more than the capital cost of many efficiency measures.

Reducing peak demand can effect building costs by reducing :

* heating and cooling plant capacity

* fan and duct size, and

* the area of potentially usable space occupied by ductwork and equipment

Unnecessarily large peak demand caused by building heating and cooling adds to utility operating costs by:

* increasing transmission and distribution losses (losses depend on the square of current flow, or the cube of gas flow)

* increasing need to utilise less efficient older plant normally kept on reserve for peak periods

* reducing the flexibility of maintenance schedules

For the building occupant, oversized equipment runs less efficiently at part load, and may cause higher noise levels.

The importance of information on energy demand profiles is illustrated by the example in Figure 1. This shows the impact on a commercial building's cooling energy requirements of installation of an economy cycle (which utilises outdoor air for cooling when possible). Clearly, the economy cycle saves the building occupant a large amount of energy (and money). However, its negative impact on utility revenue is large. Yet it does little to reduce peak demand and, hence, cost of investment in energy supply infrastructure. In contrast, double glazing and insulation work best in extreme temperatures (which helps reduce utility capital costs) but may actually increase energy bills in moderate conditions by trapping internally generated heat instead of allowing it to leak out.

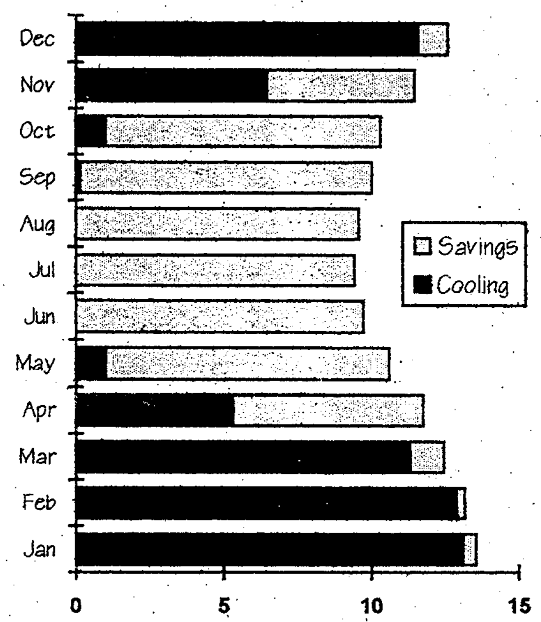

Figure 1: Energy Savings due to economy cycle cooling. Source: Hesford 1992.

(It should be noted that double glazing and insulation usually bring net annual savings, but considering only the annual savings in cost-benefit analysis overlooks their very large impact on utility capital costs and on the capital investment required for heating and cooling plant in the building.)

Economy cycle cooling is economically attractive to the occupant, but not to the utility, while the insulation and double glazing are very attractive for the utility but are often only marginally attractive for the occupant unless savings on plant capital costs and window coverings are considered.

Thus, to carry out a comprehensive evaluation of the costs and benefits of building energy efficiency measures, an understanding of their impacts on energy use profiles as well as annual savings is crucial.

Information on existing and new building characteristics

For residential buildings, survey data exists concerning the amounts of commercial fuels used to heat and cool dwellings throughout Australia. However, little of this data is based on actual monitoring. While it is reasonably straightforward to determine energy use for gas, oil and off-peak electric space heating, normal tariff electric heating and cooling are included in general tariffs. Use of statistical techniques such as regression analysis to estimate heating and cooling energy use can introduce errors due to inaccurate starting assumptions. Pears (1992) has given examples of these problems.

Even if the amount of energy used for heating and cooling is known, there is little field information available on the actual thermal characteristics of existing and new dwellings, or on the ways in which they are operated (with the exception of Williamson and Coldicutt's work on comfort preferences). Few studies have assessed the expectations and requirements of occupants for comfort and their ability or preparedness to pay for it. Thus, it is extremely difficult to establish representative usage data and model building characteristics for computer modelling.

Data for commercial buildings is also sparse and aggregated. While detailed data exists for an increasing number of office buildings, knowledge of the characteristics of the diverse range of commercial buildings is poor. This is important, as the limited data available suggest that between half and four-fifths of commercial heating and cooling energy is consumed in low rise buildings.

Factoring in heating and cooling plant characteristics

The significance of the characteristics of heating and cooling plant must also be factored into analysis. Building models simulate the energy flows through the building envelope. Heating and cooling plant characteristics determine how much metered energy is used to satisfy this requirement. Since the coefficient of performance (COP) of a heat pump varies with temperature, the amount of electricity used by this type of plant for a given amount of heat output will vary on an hourly basis. Gas or wood heater efficiencies often decline at part-load operation. Losses from ductwork or hot water pipes may vary little with reduced heating loads, while consumption of pilot lights may be a constant overhead.

To illustrate the significance of appliance characteristics in residential applications, consider the impact of a pilot light on savings. In Melbourne, the average annual gas consumption of a space heater is about 30 GJ, of which approximately 4 GJ (13%) is due to the pilot light. If the heater is 60% efficient, it can be inferred that the amount of useful heating energy supplied to the building is 15.6 GJ by using the formula shown:

$$\text{Useful energy} = \frac{\text{total gas - pilot light}}{\text{efficiency}} = \frac{30-4}{0.6} = 15.6\ \text{GJ}$$

If a mix of energy efficiency measures reduces heat loss through the building envelope by 25%, to 11.7 GJ, but the efficiency of the gas heater drops to 56%, the gas consumption would be reduced to 25 GJ, a saving of only 17%.

This difference between metered energy savings and reductions in heat flows through the building envelope has led to widespread confusion about the extent of energy savings resulting from efficiency improvement measures. It has also led to questioning of the validity of results from computer models when comparisons are made with energy use survey data. An obvious example of this problem was in Victoria, where surveyed gas savings resulting from ceiling insulation fell short of estimates based on modelling, particularly for space heated dwellings (Gas and Fuel Corporation, 1991b). While user behaviour is often credited with this lack of correlation ie. heating to higher temperatures in insulated houses, there are many other plausible explanations that relate to the nature of the heating plant.

Factors such as large increases in infiltration when ducted heating is operating - identified in US studies (Energy Design Update, 1990), temperature variations throughout spaces, and efficiency variations resulting from part-load, standby, cycling and heat distribution losses must be considered before the actual energy requirements of a building can be determined. Something as simple as locating ducted-air outlets near windows can break down the insulating film of still air next to the glass, reducing thermal resistance by up to 75% while increasing the thermal gradient across the glass.

To illustrate the potential significance of standby and distribution losses, heating energy consumption at one school visited by the author was halved by restricting the hours of operation of the boiler and reticulation pump.

Unless realistic data on these factors are integrated into modelling analysis, inconsistencies between modelling results and other data are inevitable.

Impacts of Other Building Factors

Some features installed in houses may have significant and little understood implications. For example, recent US data (Energy Design Update, 1992) suggests that installation of vented light fittings, such as recessed downlights, can create infiltration losses of greater magnitude than that through cracks around windows and doors.

Overall building thermal characteristics can be significantly affected by the selection of metal or timber window frames.

User behaviour, such as opening of windows and management of heaters and coolers, is a very important, but poorly understood variable. However, the argument that poor user behaviour can negate the benefits of energy efficiency measures is often overrated by those opposing regulation of building energy efficiency. While there is no doubt that leaving doors and windows open will reduce energy savings, regulatory evaluation should be carried out for representative, not extreme behaviour. Nevertheless, sensitivity studies should be carried out to determine the extent to which a reasonable range of behavioural factors can reduce or increase energy savings. This information may lead to greater emphasis on some measures in preference to others, and may assist in development of effective consumer information programs.

Social Issues

Residential heating and cooling energy usage is inextricably linked to social justice issues relating to the levels of comfort considered to be acceptable. Until these are agreed with social justice groups and governments, it will be difficult to incorporate them in modelling without debate. Yet their inclusion can have a critical impact on evaluation of costs and benefits.

For example, it could be argued that temperatures in bedrooms should remain within a range of 14 to 25C during sleeping hours, and that houses that cannot achieve this should pay an energy penalty equivalent to the amount of energy required to maintain temperatures within these boundaries. At present, many building industry representatives do not accept the case for specification of such minimum comfort conditions.

Since energy costs are important in evaluation of benefits, the types of fuels used by socio-economic groups can significantly affect the outcomes of cost-benefit studies. To incorporate this factor requires detailed information concerning appliance penetrations and usage in both existing and new housing.

Issues Related to Models

Existing models have obvious limitations resulting from simplifying assumptions. As with all models, this leads policy makers to place more emphasis on the factors that are modelled at the expense of other factors. Often simplifications have been made not because factors are trivial, but because of data limitations or computational complexity.

In some areas, the models may work well, but information to guide the selection of input data may be lacking. A particular example of this problem relates to comparison of performance of suspended timber and concrete slab-on-ground floors, which is extremely sensitive to assumptions regarding ground temperature. Field data is not available about ground temperatures under houses for southern Australia.

The form of output from a model can also influence evaluation of costs. For example, as noted earlier, information on peak delivered energy demand is essential for calculation of energy infrastructure cost.

For building models to become to be used more widely in government policy processes they must be accessible and easy to use. The author's own experience in this area suggests that a more market oriented approach is required in the distribution of these tools. The data input requirements and mode of data input for these modelling tools is often so tedious and has such a steep learning curve that even where government has a licence to use the software it is underutilised. Consequently the development of user friendly graphical front ends for these programs is essential. The Gas and Fuel Corporation have begun this task with promising results. Non technical staff can complete data entry over the counter for a full year ZSTEP run in 15 minutes. The use of scanning technology also promises to significantly reduce the complexity of data input.

Australian Attempts to Use Modelling for regulatory Purposes

The Victorian Experience

During preparation of its report on thermal insulation regulations for new dwellings (DITR, 1986), extensive computer modelling using Melbourne University's TEMPAL computer model was undertaken. This work clarified the range of savings likely, and investigated issues such as possible trade-offs between comfort and energy savings.

However, for the final development of the regulations, it was necessary to fall back to simple, seasonal calculations based on the methodology of Australian Standard AS2627. This occurred for a number of reasons, including lack of resources, and lack of adequate data on building, appliance and user characteristics.

An attempt was made in an Appendix to the 1990 Regulatory Impact Statement (DPUG, 1990) to correlate the savings calculated for the cost-benefit analysis with survey data and differences in building characteristics between existing stock and new homes. This included consideration of differences in floor area, use of glazing, and heated area.

The New South Wales Experience

A recent study (UNISEARCH, 1993) conducted in New South Wales has taken a much more comprehensive approach to the evaluation of costs and benefits of building energy efficiency improvement.

A Working Group agreed to use computer modelling of a representative range of buildings with agreed usage patterns as a basis for calculation of energy savings. The modelling was conducted by the University of New South Wales Solarch group, using the CSIRO-developed ZSTEP program. A detailed spreadsheet was prepared which factored in a variety of factors beyond the heating and cooling requirements of the building envelopes modelled, including:

* appliance capital cost, fuel type and efficiency
* penetrations of different types of appliance and fuel
* seasonal heating profiles
* secondary heating
* comfort take-up

* dwelling completion rates

* climatic zones where new homes are built

* dwelling characteristics (mix of modelled types)

* environmental costs of fuels

* energy production, transmission and distribution costs

This approach allows regulators to consider many of the important factors affecting the costs and benefits of energy efficiency measures. However, the consultants involved found many shortcomings in data, which means that many factors were simplified, and conservative assumptions made. For example, while the consultants found that 29% of all capital invested in the NSW electricity industry was for medium and low voltage transmission and distribution, a nominal loading of only 10% on supply costs was incorporated in the analysis.

Where to From Here?

The problems faced by those attempting to apply computer modelling to the development of regulations are often not related to the validity of the models themselves. They result from the inadequacies of data, methodological limitations and inadequate modelling of appliance characteristics (mainly in the residential sector) and lack of user-friendliness.

Much larger resources must be committed to the development of both improved, more accessible models, and improved data relating to housing stock, heating and cooling technology and usage, so the models can be applied with greater confidence.

The approach used for the recent NSW cost-benefit study shows promise to form a basis for future analyses. With improved data and more accurate information on impacts on peak demand for energy, it can provide a comprehensive assessment of the implications of application of energy efficiency measures.

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