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NEW ZEALAND BUILDING MATERIALS EMBODIED ENERGY COEFFICIENTS DATABASE
Volume II - Coefficients

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EXECUTIVE SUMMARY

This report describes the production of a database for embodied energy coefficients for BRANZ Contract 85055. The database aspects of the contract are dealt with in Volume I. The embodied energy coefficients, their background and derivation, are described in Volume II.

In 1983 NZERDC published *Energy Cost of Houses and Light Construction Buildings*.[1] This has since been used world wide as a reference document on embodied energy. The investigation was completely redone in 1995.[2] In 1997 BRANZ contracted the CBPR to extend and improve the results of the 1995 work and to develop a computer database to enable the efficient handling and updating of embodied energy information. A number of deficiencies had been identified with the 1995 investigation. The goal of the 1997 study was to rectify these deficiencies, providing a system by which an enhanced set of embodied energy coefficients for New Zealand building materials could be routinely maintained and expanded.

A database specification was developed for the collection and processing of embodied energy information. The commercial program SimaPro fits most of the criteria in this specification. The SPOLD format used by SimaPro provides an internationally recognised format for the collection and exchange of data on all environmental impacts, not just embodied energy. The program itself is in use around the world: ATHENA, Canada; BRE, UK; Eco-Quantum, Netherlands; Franklin Life Cycle Inventory, USA; Sintef environmental building, Norway. The advantages afforded by its user-friendly interface, SPOLD structured data format, encompassing of other environmental impacts and industry acceptance far outweigh the limitations of the program identified in the implementation of the New Zealand embodied energy database.

The collection of data for all environmental impacts of New Zealand building materials will be a large task, but using SimaPro it may be tackled as resources permit. The example SimaPro “project” described in Volume I, Section 4 shows, for a standard house, how embodied energy data might be used by industry. A report on say, CO_2 production or ozone depleting emissions would look the same, and would be as easy to use as this energy report.

With such a tool at their disposal manufacturers would be able to ascertain the downstream effects of alternative ingredients, in terms of embodied energy initially, and in full LCA terms eventually, given the necessary data collection. This is likely to provide some with a worthwhile marketing lever. To exploit fully this potential in the SimaPro database will require the following discrete pieces of work:

- i collection of environmental impact data for New Zealand building materials;
- ii establishment of weighting factors by which a single index of environmental impact might be constructed from the data collected in (i) above;
- iii creation of a set of standard buildings within SimaPro to facilitate comparisons of alternate building constructions for houses, commercial buildings, etc;
- iv exploration with the BIA of the feasibility of the inclusion of LCA performance specification in the NZBC.

Table of Energy Coefficients, MJ/kg and MJ/m^3

Calcium carbonate	1.3	
Cellulose pulp	14.3	
Cement, average	9.0	17 550
cement, dry process	7.7	15 020
cement, wet process	10.4	20 280
cement grout	1.9	4 560
cement mortar	2.1	3 360
fibre cement board	10.9	15 550
soil-cement	0.7	1 420
Ceramic		
brick, old technology	7.7	1 580
pipe	6.8	13 880
refractory brick	5.7	12 830
Concrete		
block-fill	1.4	3 150
block-fill, pump mix	1.5	3 430
grout	1.7	2 380
17.5MPa pump mix	1.2	2 830
Earth, raw		
adobe, straw stabilised	0.22	360
adobe, cement stabilised	0.67	1 130
clay	0.07	45
clay for cement	0.1	65
rammed soil cement	0.73	1 450
Insulation		
wool (recycled)	20.9	200
Paper		
kraft	13.9	
Plaster, gypsum	3.8	5 480
Stainless steel, average	50.4	395 640
Steel, imported, structural	35.9	281 820
Timber		
kiln dried, average, dressed	5.09	2 200
kiln dried, gas fired, dressed	8.2	3 550
kiln dried, waste fired, dressed	3.1	1 340
Water, reticulated	0.003	3.3

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1 INTRODUCTION

Volume I of this report deals with the database aspects of BRANZ Contract 85055. Volume II deals with the embodied energy coefficients aspects. It outlines the Victoria University embodied energy research that forms the basis of this database.

The hybrid analysis method used in this study, and other analysis methods are discussed. The existing manual system of analysis, before the adoption of the SimaPro database system, is described, as well as issues relating to the application of the analysis to the SimaPro database program. Avenues for further work are also presented. The appendices present: an updated and upgraded table of energy coefficients; records of materials upgraded or added since the equivalent 1995 tables; and examples of the sort of data stored in the NZEE SimaPro database on specific materials.

1.1 History

In 1983 the NZERDC published George Baird and Chan Seong Aun's report *Energy Cost of Houses and Light Construction Buildings*.[1] This publication has been used world wide as a reference document for researchers and others interested in embodied energy analysis, and is still quoted in some recent research publications.

The investigation, acknowledged by Baird and Chan to be a preliminary one, was completely redone in 1995 by Andrew Alcorn and George Baird, funded by the Building Research Association of New Zealand (BRANZ) and Victoria University. With the help of Hugh Grant, a research assistant funded by Victoria University's Summer Research Grant scheme, the total number of building materials for which embodied energy coefficients were obtained was significantly extended. These were published as *Embodied Energy Coefficients of Building Materials*.[2]

In 1997 BRANZ contracted the CBPR to extend and improve the results of the 1995 work and to develop a computer database to enable the efficient handling and updating of embodied energy information. The database aspects are dealt with in Volume 1 of this report.

Since the 1995 investigation, some of the energy coefficients listed have been superceded by changing technology in the industry, or by the closure of factories. For other materials it has consistently proved to be impossible to get data from New Zealand sources, either because it has not been collected to a sufficient level, or because commercial sensitivity persuades manufacturers to withhold the information. In these cases data had been used from overseas sources for the 1995 study. In some cases it had been impossible to get appropriate figures either from New Zealand or overseas sources.

The goal of the current study was to rectify these deficiencies, in the process of providing a system by which an enhanced table of embodied energy coefficients for New Zealand building materials could be routinely maintained and expanded.

2 METHODOLOGY

2.1 Process-Based Hybrid Analysis

Hybrid analysis was described by theorists in the early 1970s[3] but not used, as far as can be ascertained, in any large scale energy research until Alcorn developed and applied this *process-based hybrid analysis* method in the 1995 report. The hybrid system used in this study combines the best attributes of the process analysis and the input-output analysis methods, as well as incorporating statistical analysis where appropriate. The advantages are, primarily, accuracy and specificity for process analysis and a global coverage of energy transactions for input-output analysis. A description of the steps in the hybrid analysis forms Section 2.4.

2.2 Comparison of Hybrid and Input-Output Analysis

Between the Baird and Chan(1983) and Alcorn(1995) reports, there had been significant changes in technology and improvements in energy efficiency. These accounted for some of the differences between the two reports' findings on building materials' energy intensities. Far greater differences between the two reports were, however, attributable to the different analysis methods; predominantly input-output analysis in Baird and Chan, compared to process-based hybrid analysis in Alcorn.

Sawmilling is one example of improvements in efficiency during the twelve years between the reports. It is now common for sawmills to derive considerable energy from waste materials, giving an efficiency improvement to the sawmill industry in the order of 15% during the years between the studies.[4] There has also been a shift towards larger, more efficient sawmills, with smaller, older, less efficient mills closing. Over the same interval over 50% of New Zealand's cement production shifted from wet process manufacture to the more efficient dry process manufacture. In addition, new, more efficient plant was introduced to the steel industry in 1987.[5]

Due to electricity shortages, rises in the price of energy, and economic conditions generally becoming more difficult for manufacturers, the tendency has been for gains in energy efficiency in all areas of manufacturing. There are also continuous incremental improvements as new machinery is introduced. This would suggest that an across the board improvement would be seen between the Baird and Chan(1983) and Alcorn(1995) studies. This is not the case, however.

While nearly three-quarters of the materials do show a drop, by an average of 41%, the remainder show a rise averaging 46%. This is broadly consistent with a general trend to increased energy efficiency. However, the large percentage increase in more than a quarter of the figures suggests that other factors are operating. Half of the figures showed a variation averaging 64%. The main factor in the differences is the embodied energy analysis methods employed by the two studies.[6]

Baird and Chan(1983) used, for example, information from a process analysis for their cement and pre-cast concrete figures.[7,8] Equivalent figures in Alcorn, using a hybrid analysis method, show a moderate decrease, not inconsistent with the changes in the cement and concrete industry. For cement mortar and ready-mix concrete, however, Baird and Chan use an input-output analysis. Alcorn's hybrid analysis figures are significantly lower: 47% and 39% respectively.

2.2.1 Aggregation and Price Level Variation

In comparing the mainly input-output analysis results of Baird and Chan(1983) with the hybrid analysis results of Alcorn(1995), it was discovered that the principal reasons for inaccuracy of the input-output method in its application to New Zealand building materials were both the aggregation of materials with dissimilar (sometimes highly dissimilar) manufacturing methods into one "industry", and the effects of pricing. (The New Zealand Standard Industrial Classification system [NZSIC] is used by Statistics New Zealand to classify the New Zealand economy into approximately 600 industries. These are aggregated into some 80 categories for its approximately 5 yearly economic input-output studies.)[9]

The problem of aggregation can be illustrated with the "Non-Metallic Minerals" category. It comprises

> a wide range of concrete, clay, glass, plaster, masonry and asbestos products. Included are crockery, plumbing and bathroom fixtures of porcelain and earthenware, refractory insulator elements, mirrors, pottery, clay bricks and pipes, cement, lime, plaster of paris, ready mixed concrete, and concrete products such as pipes, fencing posts, blocks, tiles, power poles and special pre-cast units for the building and civil engineering industries.[9]

Some of these materials use a lot of heat in their manufacture, such as glass products, with energy coefficients of some 16 to 26MJ/kg, while others require a simple mixing of ingredients for their manufacture, such as concrete products, with energy coefficients of 0.9 to 2MJ/kg. If issues of price variation could be removed from these different materials, an input-output analysis, by having them aggregated in one category, would suggest that they all had equal energy coefficients.

The problem of price variation may be illustrated with aluminium which, because of its particular production requirements, has an extremely high energy coefficient. It has a disproportionate effect on the Basic Metal Industries category which, in the 1995 Statistics New Zealand input-output study,[10] includes primary production of all metals. The pricing of raw aluminium in New Zealand is dependent on world prices, and does not accurately reflect the large amount of energy that is used to produce it. Cheap electrical energy in New Zealand is indeed one reason for aluminium being produced here.

Price variation at the retail level can also cause input-output analysis to produce very deceptive results for particular materials. Pullen[11] quotes aluminium at 179.44MJ/kg. For aluminium foil he quotes 494.63MJ/kg. This may be taken to suggest that the process of rolling the aluminium out into foil requires 316MJ/kg or 176% of the original smelting energy. Clearly the reason is not a highly energy intensive rolling process but that foil is an expensive way of buying a kilogram of aluminium. Because foil is expensive on a $/kg basis compared to aluminium ingots, and because input-output analysis attributes energy on a MJ/$ basis, serious anomalies like the one above are not unusual. This example is from *within* an input-output analysis.

A problem of the input-output method related to price level variation is that of physical flows being assumed to be proportional to dollar flows. For example, in Baird and Chan, using input-output analysis, the figure for aggregate is very high when compared to the figure for sand. Both materials generally come from the same physical source, but sand can be expected to require slightly more processing to produce, either in crushing or simply in extra sieving and consequently can be expected to have a very slightly higher energy intensity. In this case a MJ/$ figure for the "Mining and Quarrying" category was used. Since sand and aggregate cost the same to produce and to buy, and are sold by volume, $1m^3$ of sand and $1m^3$ of aggregate will have equal embodied energy attributed to them. Since sand is some 60% heavier, however, the energy per kg appears to be much lower for sand instead of slightly higher.

2.2.2 Conclusion

Recent attempts by Treloar[12] are aimed at improving the accuracy of input-output analysis. They run the risk of negating the main advantage of the input-output method, that of being quick and simple, and making it laborious and time consuming (the traditional criticism of process analysis) while still being unable to escape the inherent coarseness of the data collection via economic survey methods. Treloar states: *"The economic sector energy intensities may be inherently unreliable, but their validity is not a direct concern* [of his report] *because it is difficult and time consuming to verify the economic sector energy intensities individually."* The approach adopted in the research reported here has been to avoid both the inherent unreliability and the time consuming verification task by using a process-based hybrid analysis.

Basing a hybrid analysis on process analysis retains the accuracy and specificity for the first, easily acquired, two or three levels of inputs which account for usually in excess of 90% of the final figure, but escapes the excessive amount of time needed to acquire the last few percent of the total. These last few percent are gained by statistical analysis or input-output analysis. The errors described above that are inherent in these last methods are inescapable, but are only applicable to perhaps 5% of the final figure.

2.3 IFIAS Levels

In the early 1970s the International Federation of Institutes for Advanced study (IFIAS) published their *Energy Analysis Workshop on Methodology and Convention* reports.[13] They identified four levels in the definition of system boundaries for energy analysis. These guidelines have been frequently used by analysts. It has been found in this study and in Alcorn(1995), however, that the IFIAS levels and boundaries definitions bear only vague resemblance to the actuality of collecting and analysing energy data. It can be difficult deciding which IFIAS level is appropriate to quote for any one energy coefficient, since the pieces of contributing data come from many different sources and may have a range of notional IFIAS levels. Consequently the practice of stating IFIAS levels has been dispensed with in this study

2.4 Existing Manual System for Computing Embodied Energy

Prior to developing a database to manage the information from energy analyses, an examination was made of the manual method used to calculate embodied energy coefficients. While there are variations for each different material, the basic approach to gathering information is similar. The following description lists the steps used.

2.4.1 Material / Product.

The product or material is clearly defined. There may be several related materials under one sub-heading, such as the various types and strengths of concrete. There may be outwardly similar materials from different sources or manufacturing processes, such as aggregate from river or virgin rock sources, that need to be clearly differentiated. The necessary distinctions and categorizations sometimes do not become apparent until some of the further information is gathered.

The use of a particular material is noted, plus the usual method of assessing the quantity used in a building: by weight, volume or area. The attributes of a material are noted as appropriate: the density, coverage per unit, specific heat, insulation value, etc.

2.4.2 Who and How Much

The major and minor players in the field are identified. This may be nationally, such as in the case of concrete production, or include international players, such as in the case of steel production. Industry umbrella organisations, such as the Cement and Concrete Association, are useful sources of information and are noted. Government departments or agencies are sometimes sources of basic, and occasionally specific, data. The total national production and the total national usage are identified, either from an umbrella organisation, or from the totals of the industry players. The quantity of material or product supplied by each player is identified. With this information a choice is made of which, or all, sources to sample for a process energy analysis.

The addresses and other contact details of all firms and organisations are recorded, along with who the contact person is within the organisation and who has given the required information. The conditions under which the information is given are also recorded. Firms often require that the origin of their information is kept confidential, although this applies more to details of their manufacturing processes than information on the state of the industry.

2.4.3 Composition

The process of manufacture and the constituent ingredients of the material are identified. Some of these constituent ingredients will be other materials from the list, such as aggregate used in concrete. Many of the ingredients, while not building materials in their own right, will require a process analysis to be undertaken to establish their energy content, such as limestone quarrying in the production of cement (as distinct from limestone as a dimension stone for construction purposes).

2.4.4 Manufacturing Process

The manufacturing process is detailed. This identifies the exact constituent ingredients and the direct energy inputs. The plant and machinery required to produce the material is also noted at this stage, in order to identify the capital equipment energy.

2.4.5 Inputs and their Values

The inputs are listed as the direct energy inputs and the energy of the constituent ingredients. The energy value of the constituent ingredients is obtained from the appropriate source or calculated from available figures or calculated through a separate process analysis for that ingredient.

All energy inputs are multiplied by the energy cost of producing that energy in New Zealand. For example, it takes 1.53MJ to produce and deliver 1.0MJ of electricity in New Zealand. Thus, a particular quantity of electrical energy used by a processing plant is multiplied by 1.53 to obtain the total amount of energy for the electrical energy input component of that process. Other energy sources (gas, coal, petroleum fuels, geothermal) have their own coefficients.(Table 1.) The tabulated energy coefficients of this report are thus in primary energy terms.(Appendix A)

Table 1 shows the energy coefficients for the production of energy in New Zealand used in this report.[14]

Energy Activity	MJ/MJ
Coal Mining	1.04
Crude Petroleum and Natural Gas Extraction	1.03
Petroleum refining	1.25
Gas Treatment and Distribution	1.1
Electricity Generation and Distribution	1.53

Transport energy may be included as part of the production process in the general energy inputs, as a separate energy input, or as part of the embodied energy figure of a constituent ingredient. Transport energy rates (MJ/net t.km) are used from published sources.[15]

The capital equipment energy of the plant and machinery is calculated using the cost and life of the plant and input-output figures from the appropriate industry category. (Current plant and equipment values are converted to 1991 dollar values to enable use of the most recently published input-output tables which use 1991 figures.)

2.4.6 Output

The output of a particular processing plant is recorded. This may be a unique output, such as aluminium from a single smelter, or a number of related outputs, such as different grades of concrete from a single batching plant. The output of a processing plant for a particular material or product is compared with the inputs to obtain the embodied energy coefficient for that material or product. Where multiple firms contribute data, each manufacturer is treated individually through to a final energy figure. Only then are figures combined to arrive at an energy coefficient for that material.

2.4.7 Prices

Where they are available, prices are recorded for retail, trade, factory gate (cost of production) and for constituent ingredients. The date of these prices is also recorded.

2.4.8 Source, Age and Confidentiality of Data

The source of data is recorded in as much detail as possible: the company it has come from; if it is published data; the person who has made the data available. The date the data was received and the time period the data relates to is also recorded. The confidentiality of data is specifically recorded and highlighted. The confidentiality requirements of the data supplier are noted. For example, the data supplier may require that the source of the data is not revealed, or that the data is only used as a component in a larger calculation which cannot be used to detect the source or details of the data supplied.

2.4.9 Other Comparative Data

Available comparative data for materials from historical or overseas sources is noted. This data quite often comes to light during the researching of a material. The particulars of this data, such as the type of analysis used to produce it, are noted. All sources and the age(s) of such data are noted.

2.5 Weighting of Data

Once data for a particular material has been collected there are often choices to be made about conflicting data items. It is often necessary to choose one figure or set of figures over another, or to combine figures but to apportion them appropriately. Factors in the reliability or applicability of data used to produce an embodied energy coefficient for a particular building material include:

- The country of origin of the data
- The country where a material or ingredient is produced
- The size of the organisation producing the data
- Political or market forces affecting the organisation producing the data
- Market or other factors influencing the period in which the data was gathered
- The relative size, within a New Zealand industry, of the organisation producing the data
- The completeness of the data
- The completeness of records from which the data is drawn
- The reliability of records from which the data is drawn
- The age of the data
- The relevance of the time period of the data
- The consistency of time periods for different pieces of data
- The level of detail of the data
- The representativeness of the factory or plant producing the data

This is not an exhaustive list but indicates the factors that need to be considered in weighting, giving credence to or choosing one set of data over another. The ultimate aim of the exercise is to produce results that most accurately reflect the current state of production of a particular material for the whole of New Zealand, in terms of energy used. The decision about whether to include particular data is made by the researcher at each step of the analysis process. The question to be answered each time is: "Does this data accurately reflect, or is it likely to accurately reflect, the current New Zealand position for this material, or is there other data available which would give a better representation of the position?" If there is better data available, within the resources to hand, it must be used.

There may be cases where data exists, without any other comparable or alternative data being available, but because of the degree of uncertainty of its accuracy it should not be used.

Clearly, data which represents a large majority of the output from a particular industry is likely to give a highly indicative energy coefficient for that particular material. A problem in sampling a large proportion of an industry, however, is that data collection accuracy is likely to vary more than data from a single carefully conducted sampling. Thus, one in-depth, specific and detailed sample can give a more reliable figure, even when extrapolated out for an entire industry, than a wide series of samples with a greater average inaccuracy. The best result, given that time and resources are always limited, may sometimes be obtained by having one very detailed sample coupled with a wide but less certain sample within an industry.

2.6 Value Ranges

Putting a percentage uncertainty figure on some of the data can be difficult. It is useful, however, to look at the range of the data and to make calculations using both the most optimistic and most pessimistic values at each step of the calculations to provide a 'High value, Low value' range. This system has been used in this study. SimaPro have also adopted this approach in their format.[16]

2.7 Influences on Energy Coefficients

Factors that have considerable bearing on the final energy coefficient are firstly whether heat, and how much, is needed in the manufacturing process, followed by the amount of physical force needed in the manufacturing process. Transport, especially if it is by an efficient means such as sea transport tends to have only a small influence on the final result. Fuel type, internal wastage and efficiency of the manufacturing plant all have a noticeable, but usually rather less significant bearing on the final result.

2.8 Materials Requiring Information

At the start of this study a list was made of the New Zealand building materials that were either missing from the 1995 study or which required further upgrading, usually because of reliance on overseas data. Clearly there are a very large number of building materials used in New Zealand and a much larger number of proprietary building products. It was evident that a selection needed to be targeted, although the final outcome of which materials it was possible to obtain sufficient data for was, and is, always uncertain. A target list of materials for which new or upgraded embodied energy coefficients would be desirable was drawn up. These were materials that relied on at least some overseas data, or had deficiencies in the New Zealand source of the data, or were notably absent from the materials listed in Alcorn(1995). The list is as follows:

acrylic - polymethyl methacrylate -
asphalt - mastic
bitumen fibre board
butyl rubber - roofing membrane
carpet - all types
ceiling tiles
cement mortar
ceramic - vitreous china
concrete - polymer fibre reinforced, pre-cast, roofing tile, steel fibre reinforced
copper wire
earth, raw - rammed soil-cement
fabrics - cotton, wool, synthetics
fasteners
GRP - polyester glass fibre laminate
glass - coated, double gazed, blocks, figured, foamed, mirror, wired
insulation - wood wool panels, mineral wool, fibreglass, polyester
paper - recycled, wall
plaster, gypsum
plastics - ABS, polyester, polypropylene
rubber - natural latex, synthetic
sealants and adhesives
stainless steel
steel - imported sections, galvanised
straw - baled
straw - compressed straw panels
taps, and other plumbing products
timber - all types
zinc

2.9 Gaps in the Coefficients Table

The response rate to requests for information from manufacturers was noticeably less for the current study compared to 1995. The reduction in cooperation appears to be a result of tighter operating conditions for manufacturers where fewer staff or less time is available to obtain the necessary information. There was also a general wariness about the commercial sensitivity of the information. This was not often backed up with a cogent reason, such as a specific competitor who may benefit from obtaining the information, but was simply a reticence to divulge information in a competitive economic environment.

One significant material for which data could not be obtained because of “commercial sensitivity” was fibreglass insulation. Since insulation is used in the vast majority of buildings constructed in New Zealand, and has a significant bearing on the energy consumed in operating a building, this is of considerable importance to an accurate understanding of the lifetime energy use of buildings.

In cases such as this overseas figures have to be relied on. Such overseas figures tend to be reasonably close to New Zealand figures for industries that have similar manufacturing processes and energy sources. In general, however, figures from New Zealand manufacturers tend to be lower than overseas ones because of this country’s easy access to natural gas and coal and our heavy reliance on hydro generated electricity, which is less energy intensive to produce than fossil fuel generated electricity, a more common source in many other countries. While available overseas data for fibreglass insulation production is likely to be similar to accurate New Zealand data, it is quite likely that the overseas figure is inflating the energy picture for New Zealand produced fibreglass insulation.

3 FURTHER WORK

3.1 Updating of the Database

Information on specific building materials and assemblies continues to come to light on a regular basis. Data on the production of primary energy, input-output tables for the national economy and surveys of various industries (transport, for example) become available from time to time. These all have a bearing on the energy coefficients of building materials. With the manual system that has been used up until now, it has been necessary to recalculate each material whenever new data comes to light. The adoption of the SimaPro computer database to manage the information means that each small piece of data can be inserted and the effects on *all* dependent materials are automatically propagated throughout the database. This means that it is worthwhile to collect small amounts of data or to devote small allotments of time, as it is available, to the database, as the results will be significant. With the previous manual system it was necessary to devote large blocks of time and effort to get results that would be accurate and have a significant bearing on the available list of coefficients.

With this database in place it is now appropriate to ask the question of how best to
a) maintain and update the database; and
b) publish the output of the database at regular, say 6 monthly, intervals.

3.2 Extending the Database into other Areas of Environmental Impact

By providing a strong framework for the data, SimaPro prompts the collection and updating of appropriate energy data. The same strong framework, by providing a series of categories of other environmental impacts, prompts the collection of data useful not only to an understanding of the energy use of buildings, but also to an understanding of the full environmental impact that buildings have over their lifetime. (See Volume I, 2.3 Energy and LCA Analysis)

The categories of environmental effects for which SimaPro analyses materials and processes are:

Energy use
Greenhouse gas emission
Ozone layer depletion
Carcinogen emission
Pesticide emission
Heavy metals emission
Solid waste production
Summer and winter smog production
Eutrophication of soil and water
Acidification of soil and water
Use of raw materials

CO_2 is probably the best target for future work. Obtaining the data necessary for its inclusion into the embodied energy database would be relatively simple. This has already been done for some of the entries, where figures existed for certain processes.[17] A detailed study of a portion of the timber industry enabled the inclusion of some detailed emissions for some timber materials.[18] This is the sort of data that would ideally be collected for all materials.

There are two issues that need to be addressed when considering extension of the database into environmental impacts beyond embodied energy. The first and most significant is the weightings and priorities that will be included in the database describing how each will be combined with all the other effects to produce a single index of environmental impact. The second issue is the collection of data on these environmental impacts.

The weighting or significance of the categories of environmental impact for New Zealand would usefully form the subject of further research. The assumptions made and the importance attributed to each category of environmental effect for the original European application of SimaPro cannot be safely applied to the New Zealand context without thorough examination. A preferable course would be to establish, from the ground up, a New Zealand database within SimaPro that used specific pieces of information from the existing SimaPro European databases after they had been found to be applicable to the New Zealand situation.

The collection of data in all fields of environmental impact could be undertaken forthwith, without the need to establish a weighting of environmental impacts. The weightings could be developed simultaneously with the new data collection. The databases that come with SimaPro should be seen as potentially valid sources of information. Much of New Zealand's plastic resin, for example, comes from Europe, and figures for it from the SimaPro databases, together with additional data such as transport inputs, could be directly applicable to the process record of plastics in New Zealand.

3.3 Example

Appendix C shows the example of *gas fired kiln dried dressed softwood,* a common material in New Zealand construction, used to illustrate how the SPOLD format within the SimaPro program stores and manages data, and the sort of manipulation and reporting from the data that can be undertaken. The full process record is provided, since the data for this material is not confidential to the CBPR, as it is contained in a report to BRANZ.[18]

The sort of graphical and numerical display shown could not be done without the database program except by expending quantities of time and effort. Equally, the traceability of the data and assumptions used in the background calculations are inherent attributes of the method.

4 Conclusion

The embodied energy coefficients database, now existing within the SimaPro framework, is at a point where the next big step in establishing useful and widely applicable guidelines for environmentally responsible building, based on sound and detailed knowledge, is ready to be taken. The SPOLD format used by SimaPro provides an internationally recognised format for the collection of data on environmental impacts. The full collection of data for all environmental impacts is likely to be a large task but using SimaPro it may be tackled as resources permit. Ongoing development of the SimaPro program by its makers can be expected to further improve the usability of the database. With these advances the uptake of the facility by the building industry and wider New Zealand public can be anticipated. The example SimaPro "project" described in Volume I, section 4 shows for a standard house how this data might be used by industry.

The potential value of the database to building specifiers and product and materials manufacturers is significant. With such a tool at their disposal manufacturers would be able to ascertain the downstream effects of alternative ingredients, in terms of energy initially, and in full LCA terms given the necessary data collection. This is likely to provide some with a worthwhile marketing lever. The ability to connect the public interest in minimising environmental impacts with a marketing potential for businesses has the potential to precipitate environmentally beneficial changes in the New Zealand building industry. It should give some companies within the industry the economic incentive to cater to public concern for the environment.

To fully exploit this potential in the SimaPro database will require the following discrete pieces of work:

- i collection of environmental impact data for New Zealand building materials for entry into the existing database structure (in the following priority order):
  - a) CO_2;
  - b) Other greenhouse gases;
  - c) Ozone depleting substances;
  - d) Pesticides;
  - e) Carcinogens;
  - f) Smog generating substances;
  - g) Solid waste, heavy metals emissions, eutrophication, acidification;
- ii establishment of weighting factors by which a single index of environmental impact might be constructed from the data collected in (i) above;
- iii creation of a set of standard building projects within SimaPro to facilitate comparisons of alternate building constructions for houses, commercial buildings etc. This work would use the earlier work of Baird and Chan (BIAC house), Treleaven[19] (5 storey commercial building) and Honey and Buchanan[20] (timber buildings);
- iv exploration with the BIA of the feasibility of LCA performance specification inclusion in the NZBC.

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ABSTRACT
The aim of the project was to generate extended and upgraded listings of the embodied energy coefficients of building materials used in New Zealand, and to provide a computer database to manage this information. A process-based hybrid analysis method of energy analysis was used for this study. The updated listings of energy coefficients for some building materials are tabulated alphabetically in units of MJ per kg, and in MJ per m^3.

Figures, Tables & References provided

SUPPLEMENTARY NOTES

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