Theme:

Title: **Automating Building Life Cycle Energy Assesment**

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Abstract: *Building designers and developers are expected to meet an increasing range of constraints on building projects. Normally, the new constraints are part of an established body of knowledge which designers either have to learn or a new "discipline" emerges which has expertise in the new area. While the stock of buildings is improved through these new requirements, both of these paths increase the complexity of the design process with consequent increases in time and cost for the project.*

LICHEE is an advanced prototype of a system that integrates CAD with life cycle energy assessment. With the addition of some extra information, it automatically estimates the operational energy and embodied energy requirements of detached housing The system was built out of existing components using the Industry Foundation Classes (IFCs) as the "glue" to bind the components together. The use of the IFCs provided significant savings in development time over writing interfaces against the major CAD systems. The software architecture chosen allowed the use of existing stand-alone software components that previously required extra expertise and time.

Keywords: *Life cycle energy, Industry Foundation Classes, Computer Aided Design*

Introduction

Increasing requirements are being placed on new and refurbished buildings as the interaction of society and the environment is better understood. These increased requirements are supported by a body of knowledge which must be understood by designers if buildings are to meet the new requirements. This places additional load on the designers with consequent time and cost implications. In some cases the body of knowledge is codified using simplified methods in order to reduce the total cost of using the methods. This often means that the methods are not applicable to non-standard designs or are ineffectual through over simplification. For these new methods to be effective, without increasing the cost of procuring buildings, methods must be found to allow designers to interact with these new bodies of knowledge.

The ability to determine the life cycle energy impact of buildings is becoming increasingly important as clients, both private and government, require reduced levels of environmental impact. However, detailed life cycle energy studies are often difficult and time consuming, leading many in the industry to make crude estimates or ignore the issue altogether. Current development work with an industry partner is establishing an automated life cycle energy analysis tool. The analysis software utilises object orientated CAD data along with life cycle, embodied energy and detailed climatic data to create an individual lifetime profile for a building design. Users are able to modify their design to explore different life cycle energy scenarios through material choice, orientation and layout.

The tool integrates several established procedures and is one of the first applications to utilise the recently developed Industry Foundation Classes (IFCs) to provide a new type of automated capability. The IFCs provide the description of the building to be analysed. The energy data used is from a series of detailed research projects that have been undertaken and represents one of the most up-to-date databases available.

This paper describes a possible approach to life cycle energy analysis through the LICHEE system which accurately analyses a house design and produces a detailed report of building elements, materials, operational energy, embodied energy and life cycle energy to create on overall lifetime energy picture of the design.

Industry Foundation Classes (IFCs)

One of the promises of the International Alliance for Interoperability and the IFCs is to provide a single method for exchanging data about buildings. The other major promise is to provide rich, structured information about the building – a building model. Both of these promises were fundamental to the development of LICHEE. Without these two promises the development of this system would not have been possible or been able to show adequate return on the cost of development.

One of the great disadvantages of many life cycle assessment procedures for buildings, or other assessment methods requiring analysis, is the need to quantify and enter data about a building into the assessment process. This can be very time consuming and as a design progresses the updating of data and tracking of changes can become onerous and error prone. Consequently, many methods are not used unless the owner/client explicitly requests their use.

Automation of data entry and utilisation of existing sources of information are of key importance if life cycle assessment is to be generally adopted. The currently emerging generation of object-based CAD systems offer an avenue for this data transfer. Traditionally, CAD drawings have been simple line representations of a building with no associated information as to what the lines actually represent, that is, walls, windows, roofs, etc. However, object orientated CAD systems do contain such information and provide the opportunity to develop automated analysis software.

Currently, assessments against NatHERS are required in a number of Australian states. These assessments are performed by qualified personnel and will mean a delay of one day in finding out if the house meets the requirements. LICHEE performs a NatHERS assessment as well as an embodied energy assessment in less than 30 seconds. This allows the designer to rapidly iterate towards a solution.

The Industry Foundation Classes (IFCs) currently being developed and implemented world-wide for information exchange from proprietary CAD systems is the future of data transfer platforms. The IFCs are a set of data exchange specifications that represent objects that occur in constructed facilities (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.). These specifications represent a data structure supporting an electronic project model useful in sharing data across applications and were adopted in the LICHEE system.

Each specification is called a 'class'. The word 'class' is used to describe a range of things that have common characteristics. For instance, every door has the characteristics of opening to allow entry to a space; every window has the characteristic of transparency so that it can be seen through. Door and window are names of classes and these classes are termed Industry Foundation Classes or IFCs. The major advantage of utilising IFC technology is that it allows analysis of drawings produced from any IFC compliant system. Many of the major CAD vendors are moving towards IFC compliance. Identification of every object in a CAD drawing by class allows analytical software calculating building performance measures such as embodied energy and operational energy to obtain almost all of the desired characteristics directly from the CAD drawing.

Life Cycle Assessment

Life cycle assessment attempts to assess the impact on the environment of any product (including buildings) from "cradle to grave", i.e. from obtaining the raw materials from which the product is created to its disposal at the end of its life. The most significant impact is usually in the use of energy and its resultant greenhouse gas emissions (mostly CO_2), with the life cycle aspect including the energy to create the product and operate it throughout its life. A full life cycle assessment includes all emissions rather than just energy and greenhouse gas emissions, including the impacts of pollutants released to the air, water and land during creation and operation.

To be able to quantify environmental impacts resulting from the construction of a building, the quantities of materials must first be estimated through a process of disaggregation to a level of detail which allows for the separation of components into their principal materials. Impact intensities of each material can then be multiplied by the quantities of individual materials and the products aggregated to obtain the total for each material, element or whole building. Consistent and reliable databases of intensities are an essential part of any life cycle assessment and it is usually where the majority of work is concentrated. A database of energy intensities has recently been derived from input-output tables and other national and international studies and is used within this study to demonstrate the principle of life cycle assessment.

Lifetimes of the materials chosen can significantly affect the total environmental impacts through materials and components having to be replaced at intervals throughout the life of a building. Thus the life cycle approach requires estimation of durability capabilities of building materials which affect the repair and replacement regimes of the components of a building. The failure of some material requires replacement of other materials which have not reached the end of their useful life. Life cycle models must include provision for such replacements to give the correct overall environmental impacts of a building over its whole life.

The life cycle operating energy requires calculation of the annual energy consumption (or environmental impact) using a reliable and proven energy evaluation technique. The operating energy calculations require knowledge of material properties such as heat transfer rates to estimate heating and cooling requirements of a building. The calculated energy of construction, operating energy and life cycle replacements and maintenance are then combined to estimate the life cycle energy. Results are usually presented as performance indicators to readily analyse and assess the impacts.

A life cycle assessment of building energy is thus a comprehensive approach which demands knowledge of construction such as quantities of materials combined with many properties of materials such as embodied energy, durability, and heat transfer characteristics. Any practical approach to life cycle energy estimation requires a fully integrated system which can be readily invoked by a user to compare alternatives. The first requirement is to obtain the relevant information from the drawings / plans for a building.

Life Expectancy & Durability

The life expectancy of building components is a key aspect of environmental indicators as all buildings require maintenance and refurbishment after construction. Estimating the actual life expectancy of a building component and associated materials is not necessarily the same as the component and materials possible life expectancy which is determined through their durability. Other life expectancy factors often interact with a component to shorten their life expectancy.

The effective durability of materials is usually controlled by the building components they are associated with and/or the building itself. For example, aluminium windows are made up of extruded aluminium for the frame, glass, weather-stripping and gaskets and window hardware (locks and latches), as shown in Figure 1. Each material has their own individual life expectancy, but some are reduced by the life expectancy of another critical material, while the component itself may have its overall life expectancy reduced by the life expectancy of the building it is installed in.

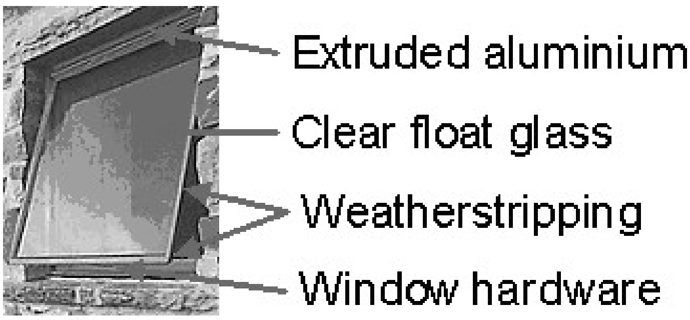

Figure 1: Components of an Aluminium Window

Table 1 shows the four main materials in an aluminium window and their relative life expectancies. The effective life expectancy of the window is determined by the life expectancy of the aluminium frame which is considered to be a critical material, that is, once it fails and requires replacement all other materials will also be replaced regardless of their condition. Thus, if this window is installed into a building with an 80 year life expectancy it can be assumed that the window will be replaced twice, once at the 30 year mark and again at 60 years.

During the life time of the window maintenance procedures are carried out which see the weather-stripping and window hardware replaced every ten years or seven times over the life of the building. The glass in the windows has a long life expectancy, but because it is replaced when the frame is replaced, its life expectancy is reduced to that of the frame and is also replaced twice over the building's life. This reduction in life expectancy can be expressed as a percentage of durability effectiveness.

Table 1: Durability Effectiveness of an Aluminium Window

Component - Aluminium Window			
Materials	**Life expectancy (years)**	**Replacements over 80 years**	**Durability effectiveness**
Extruded aluminium	30	2	89%
Clear float glass	100	2	27%
Weather stripping/gaskets	10	7	100%
Window hardware	10	7	100%

From Table 1 it can be seen that the aluminium frame has a durability effectiveness of 89% as it is affected by the 80 year life expectancy of the building which reduces the second replacement window's life to 20 years. The glass has a durability effectiveness of 27% as it is reduced by the two frame replacements and the building's life expectancy. The weather-stripping and hardware both rate 100% as their full life expectancy is achieved on all replacements.

This approach gives an indication of the effect that durability of one material within a component can have on the component's other materials. Creating components whose constituent materials have life expectancies as close as possible is an effective solution. This reduces the need for replacement maintenance and helps maximise the durability effectiveness of all materials.

The LICHEE system does factor in estimates of material and component life times along with maintenance regimes that usually exist. However, these factors are fairly broad and do not take account of local environmental conditions that may alter the life expectancy of building components. The durability of materials within certain environments is an area of research that has been undertaken by CSIRO and a database is being developed. It is envisaged that this data will be incorporated into the software to provide important additional durability information to designers.

LICHEE

The LICHEE system is not a single stand-alone package but a series of intercommunicating programs. Some of these programs, such as the Nationwide House Energy Rating Software (NatHERS), have been developed over many years and it is the integrating of these sophisticated individual programs into an all-encompassing energy analysis tool that is the real power of the LICHEE system. The main components of the system and the data flow between them (as shown in Figure 2) are:

- ArchiCAD - an object-oriented CAD architectural system with the capability of exporting files against the IFC R2.0 specification (IAI, 2000). This provides a simple method to export data in a vendor neutral way. The designer must enter a well formed building model for LICHEE to run successfully. In addition, the designer has to explicitly add “living”, “sleeping” and “un-conditioned” zones.
- The IFC processor - the core of the LICHEE system which takes the information exported from ArchiCAD, extracts the necessary information from the IFC file for both the NatHERS and embodied energy calculations, then exports the data, controls the calculation of both embodied and operating energy and initiates display of the results.
- Material quantities calculator - converts the component dimensional information produced by the IFC converter into quantities of materials. This information includes details of the component parts of the house for which they are used.

- Life cycle energy calculator - uses the material quantity information produced by the previous component to calculate the lifetime embodied energy, CO_2 and mass amounts. The embodied energy software uses material quantities, along with data on embodied energy coefficients and life times of the various house components. It also uses formula sets that allow conversion of quantities of, for example windows, into quantities of glass, aluminium, etc. All this data is combined to calculate the life time energy required by the house.
- NatHERS - Operational energy is calculated using the standard version of the simulation engine along with the building's star rating. It should be noted that the only components of operational energy calculated by this engine are heating and cooling energy requirements, i.e. the amount of energy required to be delivered to or extracted from the space to maintain the thermostat settings. The energy actually consumed by the heating and cooling equipment is estimated from the requirement by dividing by an appropriate efficiency or coefficient of performance. Other energy consumers such as hot water, lights, etc, are not considered by the NatHERS engine.
- Reporting component - reads the file produced by the processing programs and produces various tables and graphs, and summary information. It also generates a short printed report.

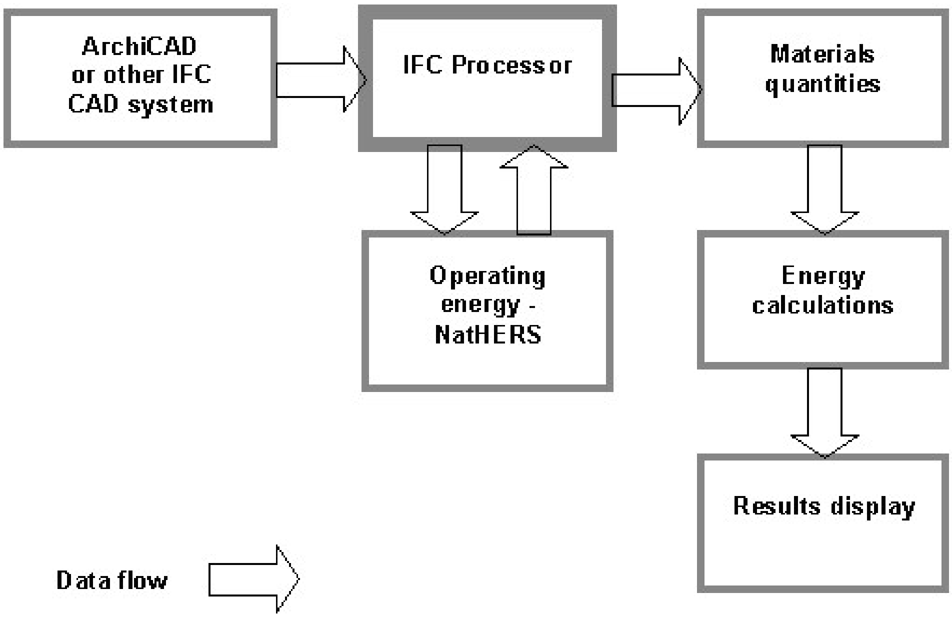

Figure 2: Outline of Software Components

Output

The reporting component of LICHEE provides the following outputs:

- Summary of results,
- Progressive graphs of life cycle energy for material groups, element and materials, in total or individually over the building lifetime,
- Cumulative graph of life cycle energy over the building lifetime,
- Progressive and cumulative tables of life cycle energy for material groups, element and materials, in total or individually over the building lifetime,
- Graphs of the total life cycle embodied energy, CO_2 and mass by breakdown of material groups, element and materials, and
- Tables of the total life cycle embodied energy, CO_2 and mass by breakdown of material groups, element and materials.

Many of the graphs and tables have the facility to click on any material group, element or material to display either the element from which it came or the materials which make up that element. Figure 3 and Figure 4 show examples of the type of graphs that the system is able to produce. Both graphs were produced from a design for a typical brick veneer home.

Figure 3 shows the cumulative annual energy of the house over its designated 60-year lifetime. It is interesting to note that the operating energy (diagonal line) overtakes the embodied energy (horizontal line) of the house after approximately 18 years and over the lifetime of the house the operating energy is more than double the entire embodied energy. Nevertheless, the embodied energy is still a significant contributor to the dwelling's total energy consumption and demonstrates the importance of total lifecycle analysis. The steps in the embodied energy line represent the maintenance and repair cycles of a typical building. The significant jump at around the 32-36 year mark represents a major repair cycle when many significant building components need replacement at the end of their effective life time.

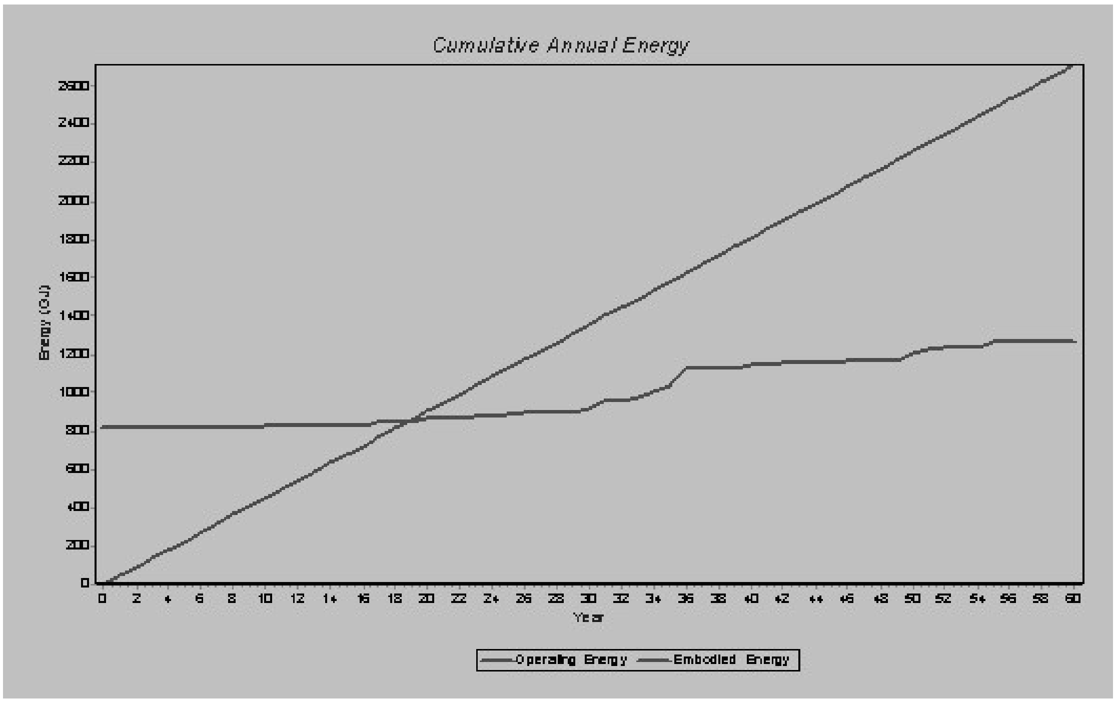

Figure 3: Cumulative Annual Energy Graph

Figure 4 shows a detailed graph identifying the contribution of the material groups to the life cycle CO_2 emissions. Similar results can be displayed for embodied energy or mass by individual materials and building elements.

Figure 4 shows that concrete is the major contributor as a material. This is due to the use of concrete in both the on-ground floor slab of the building and the use of concrete tiles as a roof cladding. The exact breakdown of the material by building element can be displayed in a similar graph by double clicking on the relevant bar in this graph. This ability to “drill down” into the displays is a fundamental need for full and informed assessment by building designers.

Once an analysis is completed the designer can go back to the building design, modify components and assemblies and then perform another analysis. As mentioned above, this ability to perform iterative design quickly and easily is necessary for the widespread use of this type of analytical method.

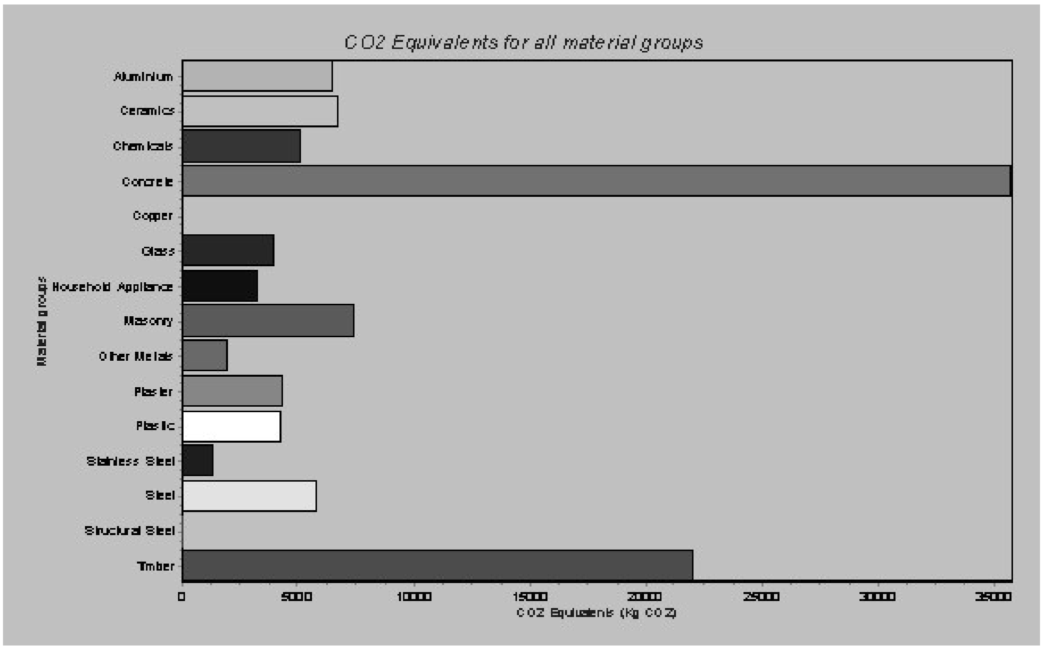

Figure 4: CO_2 Emissions for Material Groups

Future Development

The LICHEE system is presently restricted to energy calculations for residential buildings. However, it demonstrates the ability to perform analysis calculations from CAD data without the need to re-enter much of the information. Building upon such a system is relatively easy provided the data is available. For example, it is envisaged that the system will be expanded to incorporate a range of environmental considerations and enable a full environmental life cycle assessment to be performed. These could include acidification and nutrification potentials, other greenhouse gases in addition to CO_2, ozone depletion, smog, human toxicity such as carcinogens and solid waste.

Improvements in its handling of operating energy aspects are also seen as an important area. These would include:

- Adding the ability to read IFC R2x data (IAI, 2001). This will provide a wider range of choice of architectural CAD systems for input once the IFC R2x extensions become available.
- Selecting the type of heating and cooling system being used, including the option of having none. This would impact on the relative efficiencies for the various systems which is important in determining the energy consumed.
- Selecting the type of hot water system used, which again is important for efficiency.
- Setting the number of occupants in the house and selecting a user profile which determines when the house is occupied. For example, elderly people may be home all day and have a higher thermostat setting, whereas a working couple will be away for much of the day during the weekdays.
- Being able to access and modify the replacement cycle of products and assemblies for embodied energy analysis.
- Operating pollutant emissions related to choice of energy source, mainly electricity or gas.
- Adding a cost analysis component so that cost-benefit analyses can be performed.

Conclusion

The importance of life cycle assessments is increasing within a broad range of industry areas. The ability to quickly and accurately perform such assessments is going to be essential in the years to come. LICHEE is a first attempt to provide a simple and intuitive user interface to life cycle energy analyses. As users provide more feedback this user interface will improve.

Additionally, life cycle assessments are only as good as the databases that are behind them. It is imperative that accurate and reliable databases be developed for a large range of environmental factors. Material performance including durability are an intrinsic part of these databases and have a significant impact on life cycle assessment within the building industry.

The LICHEE system has been developed to allow designers quick and detailed life cycle analysis of their designs by utilising an existing CAD system coupled with a vendor free data representation format, all with little additional input. This application also demonstrates the possibilities for other building analysis work to utilise the IFC technology to gather building information and perform calculations.

The usefulness and importance of integrating analytical software packages with databases of material properties including life times based on durability has been demonstrated for a specific performance indicator, life cycle energy of houses. It is expected that expansion of the current system will see a greater variety of buildings being covered and a greater breadth of environmental impacts being analysed. This would then provide a comprehensive environmental analysis tool that would greatly simplify the assessment of environmental impacts of the built environment.

Acknowledgement

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References

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IAI, 2001, Industry Foundation Classes Release 2x