Towards an Energy Modelling Framework for Australian Cities

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Abstract: Accountable for more than 70% of the worldwide CO2 emissions (World Energy Outlook International Energy Agency 2008) and constantly growing, urban metropolises are the key actors of climate change. A rapid transition of urban areas towards energy efficiency is highly required, in particular for the building stock, which represents the main urban energy consumer. In this context, city municipalities, energy suppliers, housing companies and private owners must be mobilized and bonded around a common low-carbon urban energy strategy.

GIS simulation offers a first step into the development of this long-term strategy. It has long been applied to demographics, social and economic indicators, housing density, property costs, infrastructure, transport and water consumption. In regard to building energy modelling, it has the potential to move from a basic overview calculation down to a precise diagnosis of consumption; its causes, function, location, and time of use. Furthermore, it can allow for prediction of operational energy and carbon emission savings through identifying retrofitting upgrades and refurbishment priorities.

This study demonstrates the potential and implications of an energy modelling framework for Australian cities. A case study of a city’s CBD region that encompasses 665 buildings is modelled in 2D and 3D, comparing residential, commercial and industrial development energy prediction. Several strategies are proposed and investigated towards developing a better understanding and mapping of the energy use at a regional scale, suggesting retrofitting potential, energy targets and infrastructure capabilities.

Keywords: energy prediction; GIS modelling; city energy,

1. INTRODUCTION: WHY INVESTIGATE THE ENERGY FOR A CITY?

A nascent field of research, emerging across the globe, is one that encompasses the entire energy modelling (prediction) of a city (see references). It may be of some interest to ask why and for what purpose this activity is taking place worldwide. What does it mean to have an understanding of energy use and behaviour within our cities?

First and foremost, energy and its sources are becoming one of the prime governmental issues of importance within the times we now live in. Politics, policies and entire wars, can often be drawn to and related to the possession and control of energy. In a nutshell, our cities require energy to exist.

Therefore, one might think, that cities that have a better understanding of their energy infrastructure, their energy use period, and energy consumption, as well as an understanding of what and where the source of energy is coming from, might begin to have an edge over those cities that don’t. In fact, a proper understanding of a city’s building fabric, its building functions, and its global location, could provide dependent factors of when and how energy might be used. The realisation of energy allocation within our cities can be a revealing exercise indeed. The maximum and the minimum periods of energy supply will be realised. We will acknowledge the demands on the infrastructure that supply this energy, and whether or not they can be sustained. Ultimately, the contribution of renewable energy sources and energy storage to a more uniform and regulated energy load throughout a city would be realised.
In summary, the study of operational energy for a city is anything but a trivial and meaningless task. It is the metric of how a city is living, working and functioning. It begins to acknowledge and define the city through its building functions and classification. It also begins to consider when and where (for what buildings) energy would be used most. This project is an initial start in the right direction for decision making and future planning. We trust, that the work as presented here, will ultimately reveal the importance and the power of the subject of operational energy for a city, and lead to guidance for better planning on its behalf. The intention of this paper is to explore the potential of using GIS in conjunction with the BCA towards developing an energy modelling framework. To this end, the CBD region of an Australian city is analysed with the aid of 2D and 3D information and capabilities from GIS modelling. In this paper, the use of ‘energy’ refers to buildings’ ‘operational’ energy only.

2. CITY ENERGY MODELLING

Urban energy simulation has become a hot topic over the last decade, in part boosted by two factors: the capabilities of GIS modelling at a city scale (2D and 3D) and the computational advancements of computing processors in relation to energy calculations (Nouvel, Romain, et al., 2015). Our studies in this field seem to acknowledge at least two distinctive pathways:

- A distinctive traditional approach, normally applied to single unit energy modelling, yet, now on a much larger scale (multiple buildings).
- Other methods that consider and manipulate the information from GIS databases, covering districts, or areas, type of buildings, and their functional use.

Similarly, Reinhart et al., (2013) and Swan and Ugursal (2009) consider two approaches. The ‘bottom up’ approach is identical to our first bullet-point. This method considers ‘architypes’ based on a number of buildings pertaining to each type. The definition of the ‘architype’ is mentioned in several papers, yet, it is not explicit. Do ‘architypes’ consider building function and use as well as their wall construction? This first approach emerges from the traditional thinking of energy simulation and computational rigor for single buildings. This approach utilizes the information that the GIS modelling and database information can provide in terms of building plan area, and surface area. It also provides the orientation of each surface, its solar exposure and the levels and volume of the building.

A ‘top down approach’ according to the above authors, considers the lumping of a group of buildings as an energy sink and their operational energy use as a function of macroeconomic variables. It is claimed by Reinhart et al. that this approach is a black box and is unreliable for retrofitting interventions. Our understanding of the second method is a bit different and asks what information the GIS database could offer in terms of building type. Our top down approach initially acts as a diagnostic tool considering building classification and energy benchmarking before embarking on a more detailed analysis of individual building energy simulation. Nevertheless, both methods would benefit from actual energy consumption data, which is often difficult to obtain.

3. METHODOLOGY

The project methodology applies the Building Code of Australia (BCA) Volume One (BCA 2006). The BCA 2006 provides information on eight categories of building, as used in this study, summarised in Table 1. Volume Two of the BCA covers Classes 1 & 10, which are excluded from this analysis as they are not common to the CBD area analysed here. The BCA 2006 provided important information as to the Building Type, Energy Usage and Geographic Region. At this point in time, the BCA provided important organisational information according to the Building Class in terms of its Annual Energy Use (MJ/m²/yr) and its geographic location. Our methodology acknowledges this as one of its major strategies. The build-out analysis for this project was conducted using Community Viz, a planning and simulation tool that works in conjunction with ESRI ArcMap Geographic Information System (GIS) software package.
### Table 1. BCA Building Class Descriptions

<table>
<thead>
<tr>
<th>BCA Class</th>
<th>Class Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCA Class 2</td>
<td>A building continuing 2 or more sole occupancy units each being a separate dwelling</td>
</tr>
<tr>
<td>BCA Class 3</td>
<td>A boarding house; guest house; hostel; lodging house; backpackers accommodation; a residential hotel or motel; residential part of a school; a residential part of a health care building or a residential part of a detention centre</td>
</tr>
<tr>
<td>BCA Class 5</td>
<td>An office building used for professional or commercial purposed</td>
</tr>
<tr>
<td>BCA Class 6</td>
<td>A shop or other building for the sale of goods by retail or the supply of services including an eating room; café; restaurant; milk bar; dining room; bar; hairdresser or barber shop; public laundry; undertaker establishment; market or sales room; showroom or service station</td>
</tr>
<tr>
<td>BCA Class 6R</td>
<td>Restaurants and eatery</td>
</tr>
<tr>
<td>BCA Class 7</td>
<td>A building which is a car park or for storage, or display of goods or produce for sale by wholesale</td>
</tr>
<tr>
<td>BCA Class 8 B</td>
<td>A laboratory, or a building in which a handicraft or process for the production assembling, altering, repairing, packing, finishing or cleaning of goods or produce is carried on for trade, sale or gain.</td>
</tr>
<tr>
<td>BCA Class 9 A</td>
<td>A health care building, including those parts of the building set aside as a laboratory</td>
</tr>
<tr>
<td>BCA Class 9 B</td>
<td>An assembly building including a trade workshop, laboratory or the like in a primary or secondary school, but excluding any other parts of the building that are of another class</td>
</tr>
<tr>
<td>BCA Class 9 C</td>
<td>An age care building</td>
</tr>
</tbody>
</table>

Source: (Australian Building Codes Board 2016)

Our analysis resides in the second ‘top-down’ approach. The reasoning for this is based upon the methodologies that reside within other GIS modelling outcomes. First, buildings within the study area were categorised according to the BCA classification. The floor area for each individual building in each class was calculated using GIS modelling. An energy value was then obtained for each building using the TFA and the allowable energy benchmark, specified in the BCA, yielding a MJ/m²/annum result. Energy use figures obtained were then analysed to determine the energy use composition, patterns and distribution within the CBD area. The idea here is to exploit and improve the database in as much as possible and to describe the buildings from an energy use standpoint (Figure 1). Our approach does not necessarily abandon the ‘first principles’ or ‘bottom-up approach’ but considers acknowledging the building use and function as a primary indicator of energy consumption and possible periods of peak demand.

![Figure 1. Project flow diagram](image)

Towards an Energy Modelling Framework for Australian Cities
In the era of CO$_2$ emissions reduction and sustainable energy use within our cities, the BCA has developed sets of extensive tables that outline annual energy targets for Australian cities. These tables listed in the BCA (2006 & 2007) provide the maximum allowance of annual energy consumption (MJ/m$^2$/annum) according to ‘Building Classification’ or better understood as a building use (or type). The alignment of our work with the BCA, the main regulatory body of buildings in Australia, and embracing its classification is a unique method and powerful first step in cataloguing our buildings within urban areas. This is because a significant amount of thought in regard to building type, its operational hours, its number of occupants, its size and often even building materials has already been established and accounted for in the energy allocations. Furthermore, and perhaps more important, it is our framework in identifying and understanding our buildings and their use Australia wide.

4. ORGANISATION AND RESULTS OF A CITY ENERGY ANALYSIS

The study area represents 533,306 square metres of building space and is comprised of 665 separate buildings. The name of the city is not disclosed as consent has not been granted at this point in time. A database is structured in conjunction with other GIS information to provide the following parameters as shown in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Street Address;</td>
</tr>
<tr>
<td>Post Code;</td>
</tr>
<tr>
<td>City, State;</td>
</tr>
<tr>
<td>Name of Building;</td>
</tr>
<tr>
<td>Type of Building Area;</td>
</tr>
<tr>
<td>Number of Stories;</td>
</tr>
<tr>
<td>Overall Building Floor Area;</td>
</tr>
<tr>
<td>Building Orientation;</td>
</tr>
<tr>
<td>Length and Width of the Building;</td>
</tr>
<tr>
<td>BCA Class of Building;</td>
</tr>
<tr>
<td>Building Use</td>
</tr>
<tr>
<td>Unit Energy by Class (MJ/m$^2$)</td>
</tr>
<tr>
<td>Site Energy Use (GJ/m$^2$)</td>
</tr>
<tr>
<td>Latitude</td>
</tr>
<tr>
<td>Longitude</td>
</tr>
</tbody>
</table>

The first primary understanding within the BCA method yields the building category or classification of buildings contained within the selected CBD area. Figure 2 indicates the number of buildings in their BCA Class as well as their area for this particular city. Here it can be acknowledged that Retail (at 202,099 m$^2$) and Commercial Offices (at 169,245m$^2$) dominate the city followed by Hotels (at 52,210m$^2$) and Apartments (35,567m$^2$). It is clearly evident that other facilities, such as industry, schools or even restaurants do not comprise a substantial area as might seem apparent from initial observation.

Figure 2. Number, Area and Type of Building in Study Area
There are 149 designated residential dwellings / apartments in the study area. The majority of these dwellings are second storey apartments situated above either a retail or commercial store front. Commercial offices are the second largest category in both number and floor space (BCA Class 5). The majority of commercial offices are housed in buildings of 4 stories or less. The spatial dispersion of BCA Coded buildings in the study is shown in Figure 3. Note that retail and office categories dominate (BCA Class 5). The dispersion is random with retail disbursed throughout the CBD area.

The estimated energy use per building is associated with the BCA Classification (building class) and its annual energy use per area over a year (MJ/m²/annum). Figure 4 clearly indicates which building type or Building Class uses the most energy per unit area. It can be deducted that Restaurants and Commercial Offices require the greatest amount of energy. It may indeed seem surprising that Hotels and Apartments consume about 50% less energy than Commercial Offices.
Figure 5 Total Energy Use & Floor Area

Figure 5 illustrates the total energy use calculated using the BCA energy benchmarks and floor area for different building classes obtained from the GIS modelling. It is interesting to note that Hotels, Restaurants and Retail perform differently in their energy use as compared to the other Building Classifications. In other words, the overall energy use is significantly different from its floor area. Figure 5 prompted a further graphical analysis based upon Figure 2 which indicates whether a particular Building Class has a greater area ratio to the number of buildings in its Class. An analysis of this might indicate the feasibility of targeting a particular Building Class to reduce its energy use. For example, the Hotel (building class) has a large footprint (area) for each of its buildings. It is believed that it would be easier to target this sector for energy retrofitting. Whereas buildings in retail are far greater in number, but less in area, meaning that many different buildings would potentially require greater attention to achieve energy reduction.

What may be of interest in future analysis is the make-up of city districts that consider where commercial buildings and their classification are considered to be located according to their energy needs. It is apparent also that the period of energy use, daytime or night-time, is not evident from this information here. In terms of peak energy demand, such information would appear to be useful, so that a better allocation and distribution of energy coming from the grid infrastructure could be prepared for. The charting of energy allocated to each class serves as a first step in this direction and is useful information in preparing Figure 4. With respect to energy consumption and the expected allocation of energy to various building types, there are several interesting findings. Figure 5 indicates that the largest energy consumers within the CBD are Commercial Offices with over 189,000 GJ/annum and Retail Shops with over 164,000 GJ/annum. These two Building Classes alone account for 71% of the energy use in the CBD (see Figure 6).
Figure 6 Energy Use by Category

The site energy use (GJ/m²) was calculated for each street block in the study area. The calculation adds each building’s site energy use (GJ/m²) to produce a block total for each street in the study area. The results are (not shown here) listed for each city street block in the study area. Results are indicated and listed for all 665 buildings that were included in the study of this CBD. The grand total energy use (GJ/m²) for the CBD study area is 441,414.98 GJ/m² (total from Figure 5).

5. DISCUSSION AND CONCLUSION

The previously presented energy analysis outcomes are a component of the 2D & 3D Digital City Model of the CBD of this particular city. The key deliverables of the city building energy analysis are:

- A benchmark of energy consumption targets for the CBD. These targets are categorised by building class and by city block.
- Projected energy evaluation targets for the CBD. These targets are categorised by Building Class and by city block.
- Mapping of energy consumption ranges for selected city blocks within the CBD.

The major drivers of improved energy efficiency evolve from retrofitting existing buildings with improved materials and technology and obtaining ‘green’ power from renewable sources. In the present movement towards decentralized energy, yet, the possibility of it being clustered within the fabric of the city, distinctive changes to energy reliance from the grid are possible. This ‘additional’ renewable energy has the potential to offset peak demand loads in particular cases. Furthermore, it can reduce a total energy dependency upon the grid.

The analysis identifies opportunities to improve energy efficiency. Our methodology involves establishing building classification, taking account of particular building conditions (such as size, age and construction type). Nevertheless, it is believed that the building use and its function, is one of the key factors in its actual energy consumption. Building classification is likely to be one of the major factors ignored in traditional ‘bottom up’ methodologies that focus mainly on building fabric as believed to be the key to energy consumption. Perhaps, it is more important to consider user patterns, number of occupants, occupants schedule and operating hours when estimating energy consumption. This is in fact accounted for in the BCA method due to building classification.

Essentially, our methodology of energy analysis can be viewed as preparatory work for:

- a ‘build-out’ analysis, defined from key benchmark assumptions.
- a framework for calibrating with actual energy figures in the future.
• a basis for the estimation of retrofitting savings.
• the targeting and prioritization of buildings or regions for energy efficiency upgrades and providing a basis for better planning (build out) for energy use and requirements.

5.1 A Build-out

A build-out is an estimate of the amount and location of development allowed in an area according to current and proposed building regulations. A build-out takes into consideration natural, physical and infrastructure constraints that impact on potential development sites. A Build-out analysis enables planners to estimate the amount and location of development permitted in an area according to current or proposed zoning regulations. It provides a convenient reference for future planning, because it represents a theoretical maximum. It does not imply or forecast how many buildings will actually be built. A residential and commercial build-out of this city’s CBD, was undertaken as part of the Energy Model project.

5.2 Suitability Analysis

After the initial build-out was completed a suitability analysis was performed on the respective buildout results. A suitability analysis is the determination of which sites meet certain criteria for development or have physical constraints that restrict development. A suitability score is assigned to each location under consideration for development. Scores are assigned to a number of factors at each location. Suitability criteria include proximity to schools, parks, features of interest, hospitals and CBD, and not being close to flood areas, acid sulphate soils and industrial areas. The scoring system allows for emphasising some factors over others by assigning a relative weighting factor. The score for a factor is the assigned score times its weighting. By combining the score or each factor, at the location’s suitability score is realised.

5.3 Allocate Procedure

The next process was the allocate procedure, which takes the results from the build-out and suitability analysis and allocate the demand for buildings across the available supply of potential building locations.

Once the allocation process was completed, a series of indicators and charts were developed showing what impacts the proposed development or proposed growth would have on the CBD area. An indicator is an impact or performance measure that is applied to an entire scenario, such as total population or total energy usage. For the purposes of this report the residential and commercial build-out highlights the potential future energy requirements to the year 2031.

This paper can be viewed as an analytical tool for scoping the potential parameters of the energy efficiency opportunity based on an analysis of information and data on current building stock. Understanding and finding ways to reduce energy consumption is an important component of a sustainable smart city. Where energy production is derived from ‘dirty’ sources, reduced demand can mitigate negative environmental impacts. Reduced demand can also lead to end user cost savings, making it more attractive to live and work in an energy efficient city. One of the shortfalls in our method, as it stands at present, is the realization of Peak Demand Loads for this city. In fact, this is the next step in the analytical process, to investigate real energy data and peak loads and to verify these with predicted results.

References


