Non-residential building energy use today and tomorrow

Andrew Pollard[1], Michael Babylon[2]

Abstract

The six-year long Building Energy End-use Study (BEES) has collected detailed information on energy use for over 120 non-residential premises throughout New Zealand.

Major energy end-uses such as lighting and fixed wired appliances were measured by electrical energy measurements at the relevant circuit boards within the premise at one minute intervals. If present in the building, shared services such as lifts and HVAC systems were also monitored. Measurements were also made of selected individual plug-in electrical appliances by attaching specialised monitoring equipment to them. Additional information about the environment within the premise such as the temperature, humidity, luminance levels and CO_2 levels were also collected at a 10-minute interval. The monitoring period was typically over a two week period.

The energy use data from BEES provides a unique nationwide dataset. This paper discusses some of the characteristics of the observed energy use and possible pathways to improve the energy use in non-residential buildings. One important application for such a dataset is to provide realistic equipment usage patterns as inputs into computer-based building simulation models. These improved models will allow future building performance to be better predicted and will allow the impacts of changes to buildings and their operation to be better understood.

Keywords: Non-residential Energy Use, Energy End-Use, Building Energy Simulation, Computer Use, Appliance Use.

1. Non-residential buildings

The Building Energy End-use Study (BEES) is a study to better understand energy use in New Zealand's non-residential buildings. Defining what a non-residential building is itself a complicated question let along determining its energy use.

There is no database of New Zealand's non-residential buildings so a sample frame has to be constructed using a particular methodology. For BEES, a database of valuation records of legal titles was used (Camilleri and Isaacs, 2010). This database includes in addition to the rateable valuation information, a legal title and a usage category.

---

[1] Building Physicist, BRANZ, Judgeford, Porirua, New Zealand. Andrew.Pollard@branz.co.nz.
[2] Building Physicist, BRANZ, Private Bag 50908, Judgeford, Porirua, New Zealand.

The legal title identifies either; a land parcel, one or more buildings, parts of a building (for example, each floor of a multi-level building may have a separate title), or another non-occupied structure.

The activities within a building determine whether it is non-residential and the building category, e.g. commercial office or retail. Categorising the usage of a building can be involved. There can be a variety of activities undertaken within the building and multiple classifications may be required. This can include situations where there is a mixture of non-residential and residential uses such as apartments within the same building as retail businesses or offices. There are also more changes of tenancy within non-residential buildings than is the case for residential buildings. This can change the types of activities within in the building as well as result in varying proportions of floor area which is vacant.

Educational and health buildings have characteristics that typically make them distinct from other non-residential buildings. Commonly these types of buildings occur in clusters of buildings as part of a campus which may or may not have shared services between the buildings. For this and other reasons, educational and health buildings were excluded from the BEES sample frame (see Isaacs et al, 2009 and Isaacs et al, 2010).

2. Energy use in non-residential buildings

The varied tenancy in non-residential buildings can make collection of data on energy use complicated, as multiple energy accounts may be involved. BEES found that less than 9% of premises occupied all floors within their building (Saville-Smith and Fraser, 2012). In addition to the energy use of each of the tenanted areas within a building, there is also a base building energy use. Base building energy use is the energy used by non-tenanted activities and includes energy use for shared areas (lighting) and any HVAC plant, lifts or other services.

As a premise gets bigger, it would be expected that its premise energy use would also increase, as more areas may require more lighting, computers, office equipment, appliances and other energy services. In order to allow some comparison to be made between different premises, some scaling factor is required to correct for this effect. A common approach is to scale by the floor area of the premise. Scaling the energy use in this way produces a figure known as the Energy Use Intensity (EUI) for that premise. The energy use for the whole building (base building and premises) and the total floor area for the building could also be combined to calculate an Energy Use Intensity for the whole building (Peterson and Crowther, 2010).

3. Considering today's buildings

Until BEES the data on the energy performance of New Zealand's non-residential buildings was very limited. In the late 70's and early 80's there were a number of projects in the three main centres; Auckland (Beca Carter Hollings et al., 1979), Wellington (Baird, et al. 1983) and Christchurch (R. W. Morris & Associates, 1985), which examined the energy performance of commercial buildings in those specific areas. Making use of the results from these studies today introduces some difficulties due to the changing building standards, insulation levels and HVAC performance. These earlier studies also were localised, selecting commercial buildings in a restricted area. This has the potential to bias the sample towards larger commercial buildings.

Around the same time Standards New Zealand (1982) developed guidelines for energy efficiency in non-residential buildings which included suggesting for buildings with particular activity types such as a target of an EUI of less than 100 kWh/m²•year for new office buildings. While these targets are still frequently used today, their origins are not commonly stated, perhaps not wishing to reveal the uncertainty in these targets.

In designing new non-residential buildings, a common means to assess how it will perform with regard to energy use is to use building energy simulation computer programs. Current building code requirements allow for building energy simulation programs to be used providing they meet certain requirements (Standards New Zealand, 1996; Judkoff and Neymark, 1995).

While building energy simulation programs can provide accurate estimates of a buildings energy use, this is dependent on having an extensive data set of building characteristics, weather information and accurate schedules of HVAC, occupancy and other equipment operation. These data sources are often not available and estimates are made reducing the accuracy of the building energy modelling. Indeed often schedules and inputs from overseas are used.

Lunneberg (1999) commented that equipment load calculations for use in building simulations are frequently over estimated and that this estimate can be out by as much as five times the measured load.

Detailed measuring of equipment load demands is expensive and can only be done once the building has been constructed and occupied. This has been done within the BEES project and the BEES energy monitoring provides an opportunity to explore how appliances are actually used in non-residential buildings. This provides a better understanding of the actual appliance loads within New Zealand’s non-residential buildings and will allow better estimates to be made of aggregate appliance use for use in computer simulations of non-residential buildings.

4. Using BEES data to examine appliance loads in more detail

As part of the energy monitoring in BEES, at least three randomly selected appliances within each of the premises were measured over the two week monitoring period. These measurements were undertaken at a one-minute time interval to allow the characteristics of fast switching services to be examined in detail. For example, a refrigerator that cycles at say, a 14 minute period would always appear on if examined at the frequently used half-hourly interval.

This paper will consider computers as an example of a particular appliance load (part of the equipment load) for a non-residential building showing the pattern of typical use as well as how varied that use is.

Figure 1 is a standard exploratory data analysis (EDA) graph used within the BEES project. This type of data presentation and initial analyses supported by very high density monitoring provides an enormous amount of useful information where significant insight can be drawn from this type of data. Figure 1 shows a typical pattern of a desktop computer over twenty one days in a standard office environment. The measurement intervals are 1-minute which allows subtle patterns to be examined such as certain categories of loads (wattage), abnormalities (negative readings – either due to the inductive loads or instrument error – fluctuations, we can analyse how frequent and how significant these are), daily profiles, start and end of working hours, time and intensity of operation during each day, spikes and base loads. For example someone was working for a short period of time on Saturday 29 May and the computer was not used at all on 3 June, as it turns out this was a holiday weekend (Queen's Birthday) in New Zealand. A detailed description of these EDA graphs can be found in the BEES literature (Isaacs, et al 2010).

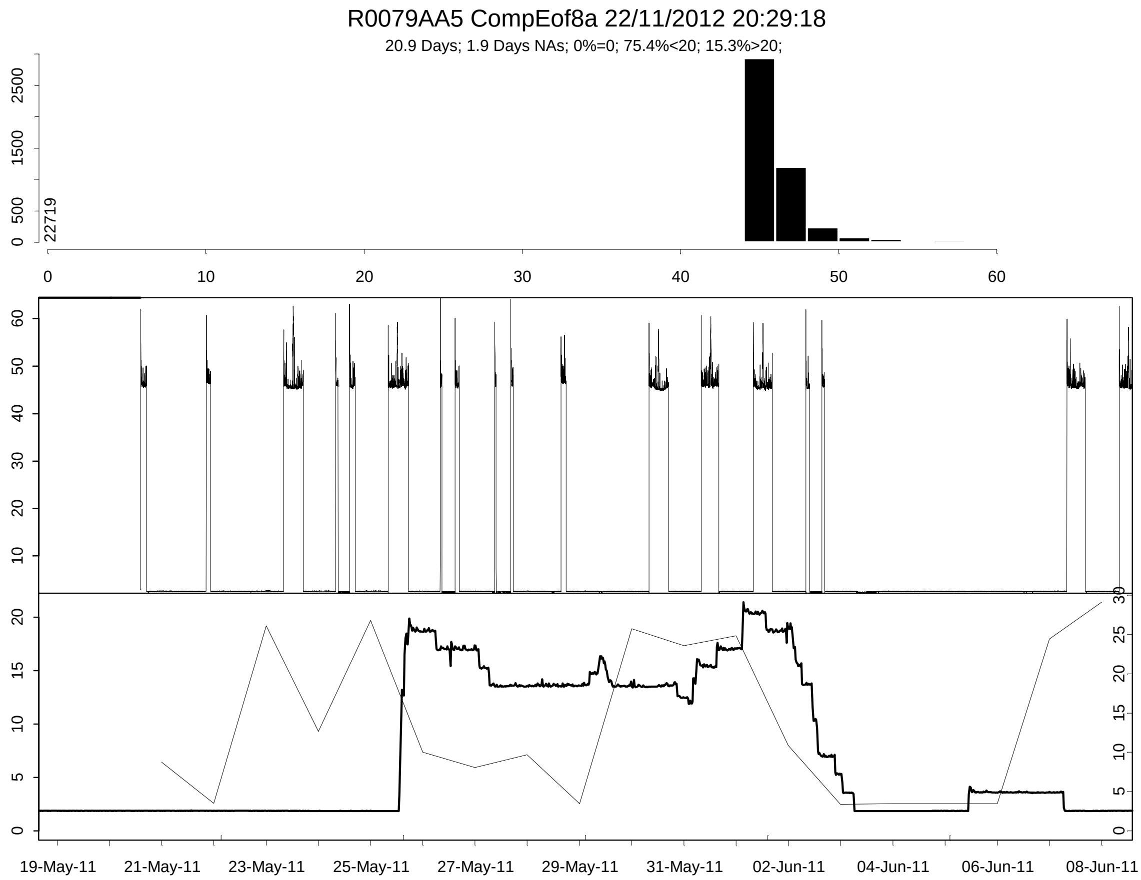

Figure 1 An exploratory data analysis (EDA) graph for a computer showing a histogram of the values in top graph, a time series graph in the middle graph and moving average (light line) and a time of day profile (dark line) in the bottom graph. These EDA graphs are routinely generated for each appliance monitored in BEES

Figure 2 gives the electricity use of one computer over one day at a one minute interval. This fine timescale allows for a detailed appreciation of “fine cycling” including clear distinctions when the processor and hard drive were performing harder. It was used in a standard office and it expected that only light processing such as word processing or basic spreadsheets were used rather than intensive processor tasks. There is a distinct but not particularly significant peak during the lunch time. Could this be lunchtime social activities which are more intensive in computer usage such as; playing games, checking social media or using the CD drive to listen to music?

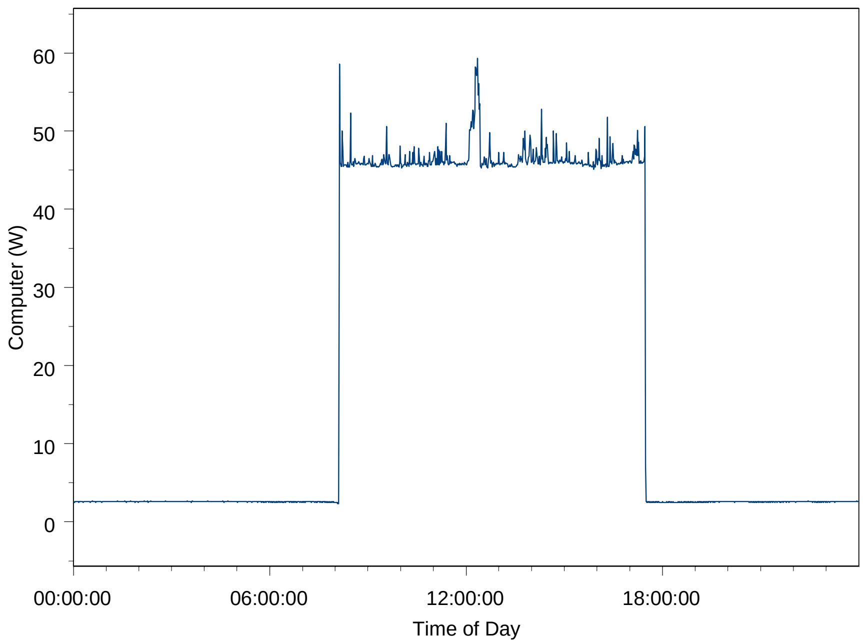

Figure 2 One day of use of one particular computer. The computer is in a low power standby mode until shortly after 8 o’clock when it leaps up to its operating level of around 45 W. After 17 o’clock the computer returns to its overnight lower power state. The interval between the data points is one-minute

The twenty-one individual days of use of the computer are presented in Figure 3 scaled to 10 minute intervals to better recognise repeated behaviours.

Figure 3 also shows in heavy black outline, the average time of day profile for the computer. This average profile is lower than the typical operating level due to the computer not always being on at that time of day. The level of the average profile will be reduced with the computer not being used on weekends and holidays as well as periods of the computer user being out of the office. The one day the computer being used in the evening results in a small blip ($^1/_{21}$ of the typical operating level) in the average profile for the evenings.

At least one feature is clearly identifiable; the computer is being used in a very consistent way and for particular regular tasks. When compared to other computers in the building, we observed similar profiles. Thus at least in this case it is quite simple to estimate the profile and the way the energy is used by computers in this business.

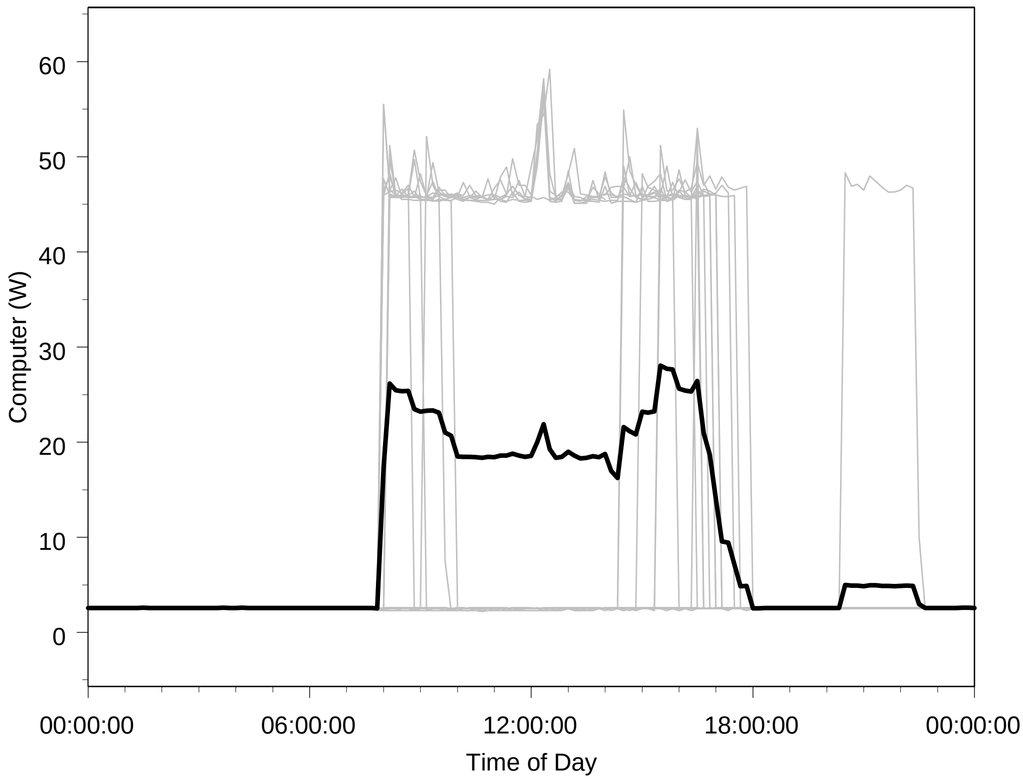

Figure 3 Twenty one days of the use of one computer shown superimposed (in grey) by time of day with the resulting time of day average profile shown in heavy black outline. The time interval has been changed to 10 minutes to emphases the underlying patterns.

For the purpose of this analysis we have selected fifteen computers in different premises available from the BEES database. Two thirds of these computers were in offices with the remaining third in retail premises.

Figure 4 gives the value of the estimated annual energy use (in kWh) of the fifteen computers examined in descending order. Computers present in offices are identified by the dark grey bars whereas computers in retail business are identified by the light grey bars. These computers were for individual use and did not include a display other than when this was an integrated feature of the computer (such as a laptop). The energy is collected when the computer is used at the monitored premise. Laptops which are used away from the premise will only have the data from when the computer is present at the business recorded. The monitoring for the laptops is not of the operation of the laptop (as laptops can operate from batteries) but instead is when the computer is connected to an electrical outlet and using electricity.

The top three (20%) computers in the energy rankings were computers that were left on outside of the business hours. This 20% is similar to the proportion of computers in the United States of America that were identified as being ‘on’ outside of normal hours (Webber, 2005). These three computers use considerably more energy per computer than is the case for any of the other computers. The three laptop computers (ID’s 10,12 and 15) were lower energy using computers. The highest energy using computer used more than forty times the energy than of the lowest energy using computer.

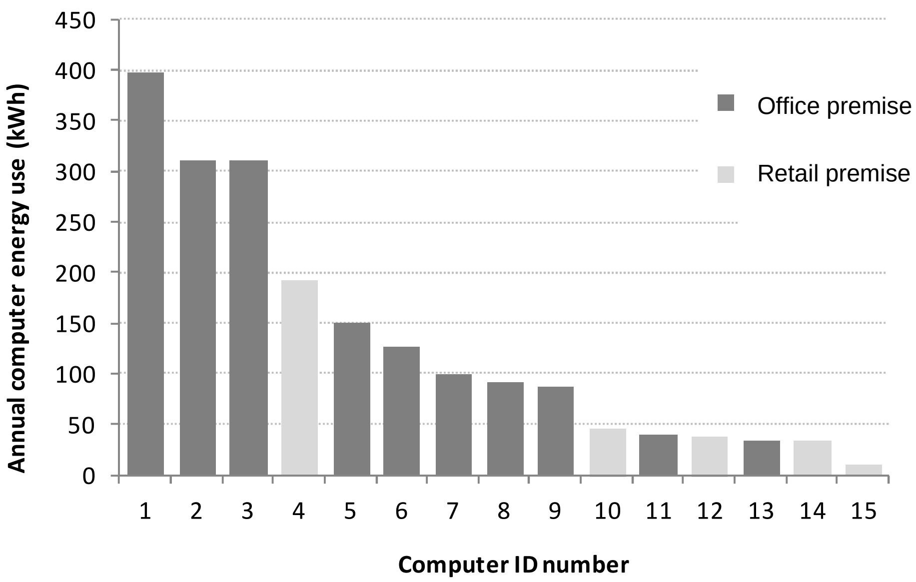

Figure 4 The estimated annual energy consumption of fifteen computers from non-residential buildings (excluding energy use for any separate screens).

Figure 5 gives the electricity time of day demand of fifteen different computers. Apart from the three computers that are left on outside of working hours, and the lowest energy using computer shown in the bottom right hand corner of Figure 4. All of the computers show an approximate square wave shape increasing energy use from around 8-9 o’clock in the morning and running until around 17-18 o’clock before dropping back to a standby load level outside of working hours. The differing factors for each of these computers are the power requirements during the operating houses as well as the varying standby power requirements outside of normal hours. The standby load varied from around 2 W to 10 W. One system appeared to have no power requirements outside of operating hours. It is likely this system was turned off at the end of the day rather than being set to standby.

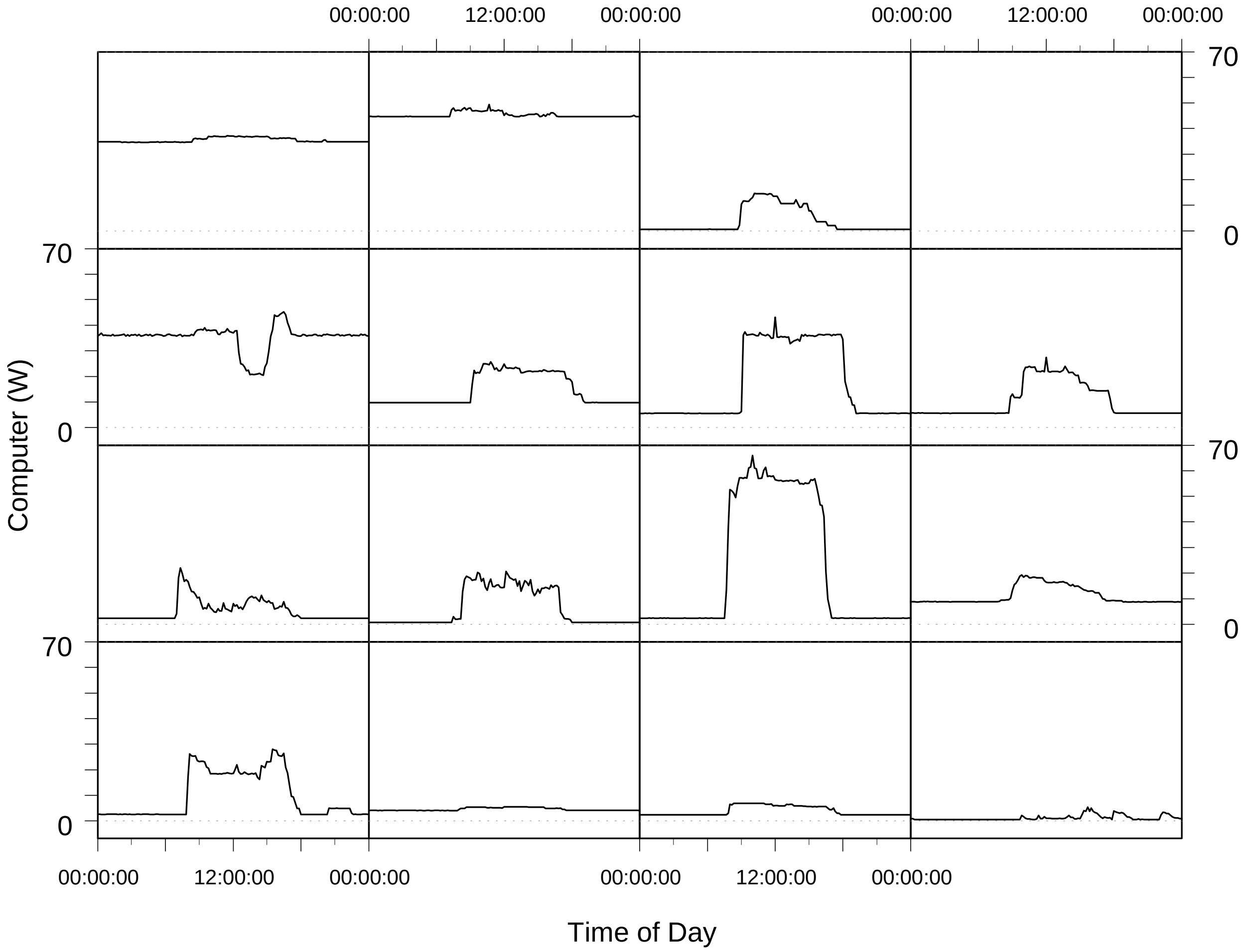

Figure 5 Computer power demand by time of day for fifteen separate computers (excluding any separate screens).

5. What this means for buildings for tomorrow

Building energy simulation is currently the primary means to examine the energy impacts of various building design options. While building energy simulation programs accurately determine the physical heat transfer processes going on within a building, they are dependent on having accurate information on the operational characteristics of the building such as the occupancy, HVAC and other equipment use.

The BEES data is revealing some of the variability present within equipment operation which will allow more realistic equipment schedules to be developed in the future.

The operational characteristics are ultimately dependent on the people using the building. While using more accurate equipment schedules will allow a more accurate calculation of the building energy to be made, there still may not be sufficient variation in the scheduling to accurately summarise the collective behaviours of the building uses. A framework to better understand building energy will require drawing together physical building energy simulation models with behavioural models of what the users of the building are doing.

One emerging method to examine behaviours of a set of individuals is agent-based modelling (Macy and Willer, 2002). Agent-based modelling uses large scale computer based calculations of a set of basic rules on a number of agents within a target population. Agent-based modelling has had some application to energy use in buildings. Azar and Menassa (2012) is one such example, however this paper looked to examine the impacts of behavioural change, turning high energy consuming users into low energy uses, rather than in better understanding the overall operation of a building. Perhaps there is an opportunity for agent based modeling to be used to provide a range of operational schedules for input into building energy simulation models in an analogous way to have varying weather data is examined by considering a full year of data.

Building energy simulation provides a means to assess the energy impacts of a variety of design choices. Building energy simulation can be used to set targets for the energy use for a particular building by setting a level of maximum energy use that can only be achieved by incorporating good thermal design and a well performing HVAC system into the building. Care must be taken to ensure that a building’s actual operating energy use is aligned with its design levels. Turner and Frankel (2008) highlight that this is not always the case with many ‘high scoring’ buildings actually requiring more energy that is set as a maximum for the code requirements (see figure ES-5 in Turner and Frankel, 2008).The overall energy use in the BEES buildings will provide some indication of variability of real building energy performance. This performance information will help to inform the setting of any performance thresholds for new buildings but would also assist the setting of targets for the retrofitting and upgrading of existing non-residential buildings.

The Energy Efficiency and Conservation Authority (EECA) and the New Zealand Green Building Council (NZGBC) have announced (EECA, 2012) that they will be developing a New Zealand version of the Australian NABERS (National Australian Built Environment Rating System) scheme which looks to assess buildings on their measured energy performance. BEES has provided energy use intensity information to the developers to assist with benchmarking against standard New Zealand buildings.

6. Acknowledgements

BEES is funded by BRANZ Ltd. through the Building Research Levy and the Ministry of Business, Innovation and Employment through its Building and Housing group and its Science and Innovation group. The Energy Efficiency and Conservation Authority (EECA) has also contributed to the funding for this project.

References

Azar, E and Menassa, C (2012) 'Agent-Based Modeling of Occupants and Their Impact on Energy Use in Commercial Buildings', *J. Comput. Civ. Eng.*, 26(4), 506–518.

Baird, G, Donn, M and Pool, F (1983) 'Energy demand in the Wellington central business district'. New Zealand Energy Research and Development Committee. Report 77, February 1983. ISSN 0110-1692.

Beca Carter Hollings and Ferner and R Shaw. (1979). *'Greater Auckland commercial sector energy analysis. New Zealand'* Energy Research and Development Committee. Report 45, May 1979. ISSN 0110-1692.

Camilleri, M and Isaacs, N (2010) "The Building Energy End-use Study (BEES): Study Design and Early Findings" *Proc. CIB 2010 World Congress*, 10-13 May 2010, Salford Quays UK.

EECA (2012) 'Office building rating scheme coming to New Zealand' http://www.eecabusiness.govt.nz/content/office-building-rating-scheme assessed 21 November 2012.

Isaacs, N (ed.), Saville-Smith, K, Babylon, W M, Bishop, R, Camilleri, M, Donn, M, Jowett, J, Moore, D, and Roberti, J (2010) '*Building Energy End-Use Study (BEES) Year 3*', BRANZ Study Report SR 236, BRANZ, Porirua.

Isaacs, N (ed.), Saville-Smith, K, Bishop, R, Camilleri, M, Jowett, J, Hills, A, Moore, D, Babylon, W M, Donn, M, Heinrich, M, and Roberti, J (2009) '*Building Energy End-Use Study (BEES) Years 1 & 2*', BRANZ Study Report SR 224, BRANZ, Porirua.

Judkoff, R and Neymark, J (1995) *'International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method'*; NREL/TP-472 6231, National Renewable Energy Laboratory Colorado, USA

Lunneberg, T (1999) *'Improving Simulation Accuracy Through the use of Short-Term Electrical End-Use Monitoring'* Proceedings of the International Building Performance Simulation Association Conference 1999.

Macy, M W and Willer, R (2002) 'From Factors to Actors: Computational Sociology and Agent-Based Modeling', *Annual Review of Sociology* Vol. 28, pp. 143-166

Peterson, K and Crowther, H (2010) '*Building EUIs*', High Performing Buildings, Summer 2010, ASHRAE.

R. W. Morris & Associates. (1985) *'Commercial sector energy use in Christchurch'*. New Zealand Energy Research and Development Committee. Report 115, September 1985. ISSN 0110-1692.

Saville-Smith, K and Fraser, R (2012) '*Building Energy End-Use Study (BEES) Interim Report: Buildings – Size, Management and Use'.* BRANZ Study Report SR 277/1, BRANZ, Porirua.

Standards New Zealand (1982) '*NZS4220:1982 Code of practice for Energy Conservation in Non-Residential Buildings'.* Standards New Zealand, Wellington.

Standards New Zealand (1996) '*NZS4243:1996 Energy Efficiency – Large Buildings'.* Standards New Zealand, Wellington.

Turner, C and Frankel, M (2008) 'Energy Performance of LEED® for New Construction Buildings', Report for: U.S. Green Building Council by the New Buildings Institute, Vancouver, Washington, USA.

Webber, C A, Roberson, J A, Brown, R E, Payne, C T, Nordman, B Koomey, J G (2005) 'Field Surveys of Office Equipment Operating Patterns' Report LBNL-46930, Lawrence Berkeley National Laboratory, Berkeley.