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MODELLING NET ZERO ENERGY OPTIONS FOR A SUSTAINABLE BUILDINGS RESEARCH CENTRE

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ABSTRACT

The Sustainable Buildings Research Centre (SBRC) currently under development at the University of Wollongong will be an exemplar in respect of demonstration of a range of technical and operational means of reducing greenhouse emissions and other ecological impacts. This paper details the constraints and opportunities presented to the project in terms of renewable energy production and minimization of building energy consumption. The building performance was simulated using variety of tools for a range of ventilation and air conditioning options. Energy generation and demand management options considered include: earth-to-air heat exchangers; ground source cooling and heating; building integrated solar air heaters; natural and mixed mode ventilation schemes, etc.

INTRODUCTION

In recent years the imperative to drive down energy use in buildings and associated greenhouse emissions has resulted in: a) much greater emphasis in building design and operations for maximisation of energy efficiency measures and; b) increasingly stringent government regulation of both new and existing buildings. A recent example of market mechanisms being utilized by Australian governments to increase energy efficiency of buildings is the introduction of "Mandatory Disclosure" whereby all commercial buildings and lettable spaces exceeding a given floor area (2,000m^2) are required to obtain, and display in advertisements, an operational energy performance rating (CBD 2011).

As overall building energy efficiency has increased the possibility that commercial/educational buildings may be able to be fully powered by on-site generation has now developed, indeed some net zero-energy buildings have become a reality. This move towards net zero-energy buildings or nearly zero-energy buildings has resulted in significant discussion about their definition and whether governments should legislate to encourage their development. There are a number of different definitions of net zero-energy buildings, four that are frequently cited are as follows (Torcellini, Pless et al. 2006):

a) Net Zero Site Energy – at least as much energy is generated on site as is used by the building;
b) Net Zero Source Energy - at least as much energy is generated on site as is used by the building from sources on and off-site, including the energy required to bring the energy on-site (e.g. transmission losses, transport, etc);
c) Net Zero Energy Costs – the amount the utility pays for exported energy generated on site is greater than is paid to the utility for energy imported to the site;
d) Net Zero Carbon, Net Zero Emissions or Net Zero Energy Emissions – is where the emissions from energy produced on-site or off-site from fossil fuel are balanced by the production of renewable energy on-site.

It should be noted that the above only deal with operational energy/emissions, however, embodied energy/emissions may also be included.

In Europe there are very strong pressures for the building sector to move quickly towards nearly zero-energy buildings. The current European Climate and Energy Objectives are to effect a 20% reduction in greenhouse gas emissions and 20% in energy savings (relative to 1990 levels) and a 20% share of renewables in the energy supply mix, all by 2020. Recently the EC mandated that all new buildings should be "nearly zero-energy" (EC 2010).

Key constraints and technologies involved in Net Zero Energy Building Development

At present the marginal emissions abatement costs for energy efficiency measures are far cheaper than for on-site renewable generation technologies. For example, recent estimates indicate that replacement of old air conditioning (HVAC) plant in an existing commercial building in Australia saves the owner/tenant about A$120 per tonne of CO_2 abated, versus the extra cost of using centralised solar photovoltaics for power generation, at an estimated cost of $90 per tonne of CO_2 avoided (ClimateWorks 2010). Thus, any cost effective realisation of a net zero energy building will require, first and foremost, the maximisation of passive solar design features and energy efficiency initiatives, before sizing of the on-site generation requirement can be finalised. These requirements pose considerable challenges for designers, particularly when faced with short project design timeframes, which are becoming increasingly the norm.

Accurate modelling of the energy consumed by the building using transient energy analysis simulation tools becomes increasingly difficult as net energy consumption is minimised. This is because of the uncertainties that are inherent in both the simulation tools, the local climate and in the eventual operation of the building. For example, minimization of building energy consumption is likely to involve the maximum use of natural ventilation and mixed-mode HVAC systems. Natural ventilation is of course much more difficult to model than conventional mechanical systems and requires detailed knowledge of the local microclimate.

Frameworks to assist in design of sustainable buildings

A wide range of tools are used for rating and assessment of the ESD performance and environmental impact of buildings. In Australia the Green Star design tool developed by the Green Buildings Council of Australia (GBCA 2011) is recognised as the key design tool for buildings in a number of categories such as commercial, educational, healthcare, etc. This tool requires detailed thermal modelling of the building. The National Australian Built Environment Rating System (NABERS 2011) is used to rate a building's performance in terms of operational energy and water usage and Indoor Environmental Quality (IEQ). Other tools that have been applied on the international scence include LEED and the Living Building Challenge in the US, and PassivHaus and MinEnergie in Europe.

So as to make the largest emissions reductions for a given building budget it is generally accepted that a building design team should approach design of a very low energy/emissions building using the following approach: i) first reduce internal gains and improve envelope performance to minimize HVAC loads; ii) optimise the HVAC system design; iii) when the building energy loads have been minimised as far as possible then provide an on-site or off-site renewable energy supply. This approach was adopted on the present project.

The UOW Sustainable Buildings Research Centre

The Sustainable Buildings Research Centre (SBRC) is currently under development at the University of Wollongong (UOW) which is located approximately 80km south of Sydney. The SBRC will form part of a local initiative funded by the Australian Commonwealth Government that focusses on the upgrade and retrofitting of existing buildings for sustainability. This initiative is entitled the Retrofitting for Resilient and Sustainable Buildings (RRSB) program, which is supported by a \$25.1m capital works grant to UOW through the Education Investment Fund (EIF) and administered by the Department of Innovation, Industry, Science and Research (DIISR). The RRSB program comprises four key components: a) the Sustainable Buildings Research Centre; b) new vocational training facilities for TAFE NSW to assist in the development of their capability in retrofitting training of trades persons and para-professionals; c) a demonstration and research program whereby a number of existing dwellings close to the SBRC will be monitoried before and after a range of retrofitting programs for energy and water sustainability; d) a "distributed retrofit program" on the main campus of the University of Wollongong.

Figure 1 SBRC Building concept design (two storey office at lower right, high bay labs at upper left).

The purpose of the SBRC building is to house researchers from both academia and industry and to incorporate a wide range of laboratory and test facilities. The latter will include: a large scale integrated component testing laboratory; an electrical power quality, renewable generation and storage laboratory; a water sustainability laboratory; thermal analysis and simulation laboratory; roof top test area.

PRELIMINARY SIMULATION OF SBRC THERMAL PERFORMANCE

UOW is targeting a Six Star Green Star rating for the SBRC building using the GBCA educational rating tool. However, given that this level of environmental performance will undoubtedly be surpassed by such buildings in the near future, the design team decided to also target Living Building Challenge accreditation (ILBI 2010). The Living Building Challenge provides a somewhat different framework to GreenStar and in many aspects is a significantly more stringent rating tool. One of the key challenges in achieving such accreditation is the requirement to achieve Net Zero Energy.

This desired goal could only be achieved within the given budget constraints if the building design incorporated significant passive design features and high efficiency building envelope, but also that all equipment, lighting and plug loads be drastically reduced from the standards current in Australian new-build facilities.

Configuration of the SBRC building

Following initial analyses of the functional requirements of the building and inclusion of site constraints, an overall design concept for the SBRC was developed. The building will comprise two rectangular wings, each with the long axis orientated east-west for optimal solar access and shading as shown in Figure 1 and Figure 2. The southern "office" wing has been designed as a two-storey structure with the top floor as an open plan office and the ground floor will include an exhibition area, training room, two single-storey multi-function laboratories and service areas. The second wing will be a high-bay facility with flexible functional capability, housing large-scale equipment, including a wind tunnel, and a gantry crane operating over the full length of the building.

Natural and mixed mode ventilation

Given that the temperate coastal climate at Wollongong is relatively benign, the starting point for the design of the SBRC Building was a specification that the use of natural ventilation should be maximised and that mechanical ventilation, heating and cooling would be implemented only if necessary.

Figure 2 SBRC Building concept design showing wind turbines and PV arrays to north of high bay.

Preliminary energy consumption analysis

The first stage in the assessment of whether Net Zero Energy operation of the SBRC could be achieved was preliminary benchmarking against similar buildings and in particular the NABERS energy rating scheme (NABERS 2011). The results presented in the present paper represent a preliminary analysis of the two-storey office block, which will be the main consumer of energy on the SBRC site. The gross floor area of the office block is approximately 1625m^2. Table 1 provides some current measures of energy performance for an equivalent office in Sydney using the NABERS (NABERS 2011) reverse calculator and some design guidance figures used in the industry (AIRAH 2007).

A number of design workshops resulted in significant improvements to envelope performance, *cf* strategy i) above. A number of transient thermal analyses were then carried out on the two-storey office wing of the SBRC building using the DesignBuilder simulation software. Preliminary results are presented in Figure 3. Case 1 is the base case with the normal university IT solution and no sophisticated lighting control system. Case 2 involves a Green IT solution using "thin client" technology software/mobile phones, etc. Case 3 is the same as Case 2 but with the addition of sophisticated daylighting control systems.

Table 1 Benchmark figures for office buildings in the Sydney region (AIRAH 2007; NABERS 2011).

Building type	Energy consumption (MWh/yr)	Energy consumption (kWh/m^2/yr)
NABERS 4 star (whole building)	406	250
NABERS 5 star (whole building)	278	171
AIRAH best practice existing building	243	149
AIRAH new building design target	181	111

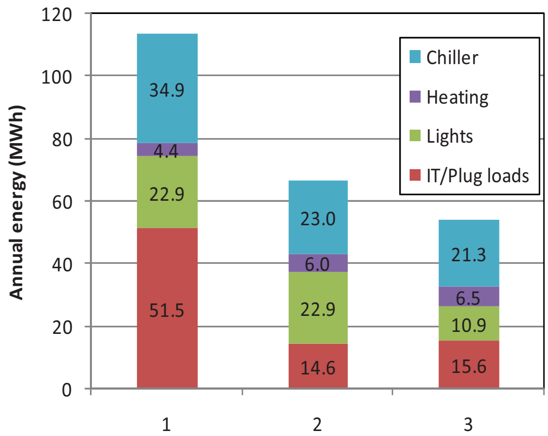

Figure 3 Preliminary annual energy consumption predictions for three IT/lighting scenarios in the two-storey office wing of the SBRC building.

These preliminary simulations involved a number of assumptions as to the form of the HVAC system (assumed here as a typical VAV system) and excluding lifts, external lighting, etc the resulting energy use intensity for the three cases were 70, 41 and 33kWh/m^2, respectively. This demonstrates that adoption of low energy IT solutions and sophisticated daylighting control throughout the building could potentially reduce energy consumption by ~50% leading to significantly less PV required to achieve a Net Zero Energy building.

EARTH-TO-AIR HEAT EXCHANGER MODELLING

Earth-to-air heat exchangers (or "labyrinths") have been used to reduce the amount of cooling/heating required for fresh air tempering in various styles of architecture over many years, even centuries. As part of strategy ii) above the present authors modelled the use of one or more earth-to-air heat exchangers as remote thermal mass and for tempering incoming ambient air. Interest in the analytical and numerical modelling of these devices has increased in recent times, as exemplified by the theoretical modelling reported by Hollmuller (Hollmuller 2003) and more recently the development of algorithms for incorporation in building simulation packages such as EnergyPlus (Lee 2006; Lee and Strand 2008).

Recent examples of earth-to-air heat exchanger applications

A number of low energy and Net Zero Energy Buildings have recently been designed with earth-to-air heat exchangers incorporated. A good example being the recently completed Research Support Facility (RSF) at the National Renewable Energy Laboratories (NREL) Golden, Colorado (NREL 2009). Here a basement was used as an earth-to-air heat exchanger under almost the entire building with walls acting as baffles to form a labyrinth. Other buildings reported recently with earth-to-air heat exchangers include the Davis Alpine House at Kew Gardens, UK, and Federation Square in Melbourne, Australia (Bellow 2006).

Finite difference 2-dimensional transient model

The present first author had previously developed a finite difference code to model the transient thermal behaviour of buried gas pipelines during hydrostatic testing (Arfiadi, Cooper et al. 2001). For the present project this code (implemented in Fortran) was enhanced so as to model the transient performance of earth-to-air heat exchangers. A full numerical model of an earth-to-air exchanger would involve a full conjugate heat transfer (conduction/convection) Computational Fluid Dynamics (CFD) transient simulation. However, the computer run times required for such a simulation are currently prohibitive for building design purposes. Thus, an approximate approach was taken, assuming that the exchanger was a circular buried horizontal pipe. A cylindrical system of coordinates was then used to model conduction heat transfer in the pipe wall and surrounding soil at a large number of cross-sections along the length of the pipe, with the assumption that the pipe was buried at a sufficient depth that the effects of diurnal fluctuations in soil surface temperature were not significant. Axial conduction in the soil was neglected and the air-side forced convection heat transfer coefficient was calculated using the well established Dittus-Boelter equation. This is an approach similar to that taken by others such as Mei (Lee 2006).

The properties of the soil at the SBRC site were estimated from previous qualitative geotechnical surveys of the site and with reference to ASHRAE data on the thermal properties of soils (Kavanaugh and Rafferty 1997). The range of soil properties likely to be found at the SBRC site are thought to be between the extremes of soils SBRC A and SBRC B in Table 2. (Note: on-site thermal testing needs to be carried out for an accurate assessment of soil properties). Also shown in Table 1 are the properties for a range of soils used in the EnergyPlus "Earth Tube" module which was compared against the present finite difference model, as described below.

Table 2 Soil properties around the earth-to-air heat exchanger (Kavanaugh and Rafferty 1997; EnergyPlus 2010).

Soil Type	k (W/mK)	α (m^2/s)
SBRC A	1.9	1.10E-06
SBRC B	2.7	1.00E-06
EPlus Heavy, Saturated	2.42	9.04E-07
EPlus Heavy, damp	1.3	6.45E-07
EPlus Heavy, dry	0.865	5.16E-07
EPlus Light, dry	0.346	2.80E-07

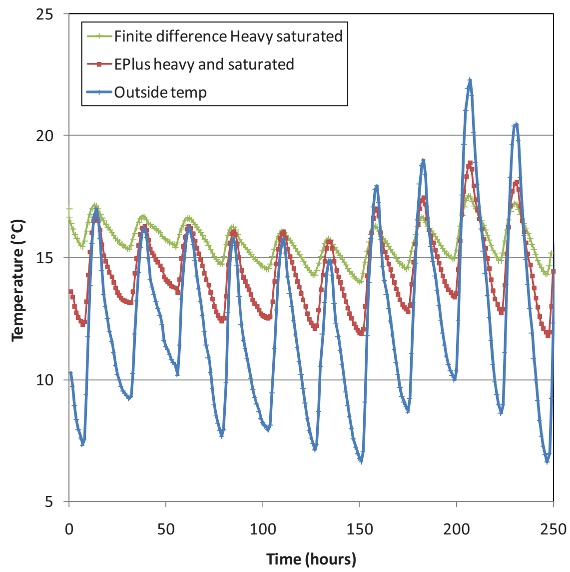

Figure 4 Simulation of air exit temperatures for a 100m-long cylindrical earth-to-air heat exchanger for typical winter conditions and assumed T_{soil}=18°C and two different soil types.

Preliminary results of the 2D finite difference model simulations are shown in Figure 4 and Figure 6 for a simple cylindrical pipe, 100m in length and with an internal diameter of 660mm, carrying 684L/s of outside air. The pipe is assumed to have the same thermal properties as the surrounding soil. The outside (inlet) air temperatures were taken from the weather file used in the thermal simulations during winter at the SBRC site.

Figure 4 shows how the earth-to-air heat exchanger greatly reduces the diurnal swing in ambient temperature and will potentially reduce the heating and cooling loads required in the building. It also shows that the influence of the likely variation in soil properties is relatively minor. Figure 5 shows the heat transfer from the air (negative values mean the air is being heated by the surrounding soil). It can be seen that the rates of heat transfer are predicted to be relatively modest, even though the exchanger is 100m long, and that the variation in soil properties between "heavy and saturated" and "heavy and damp" makes relatively little difference to the rate of heat transfer.

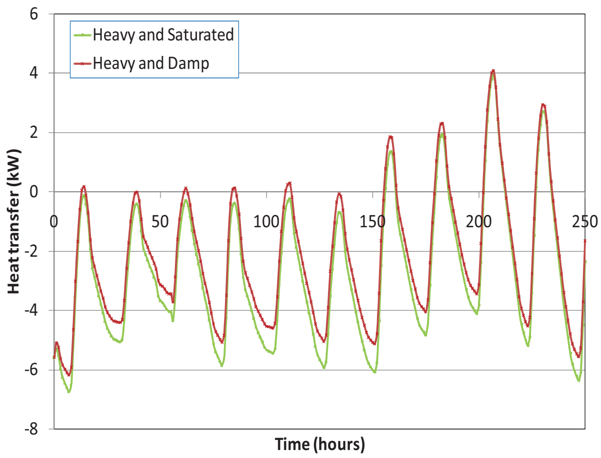

Figure 5 Heat transfer from the air to earth for same situations as shown in Figure 4.

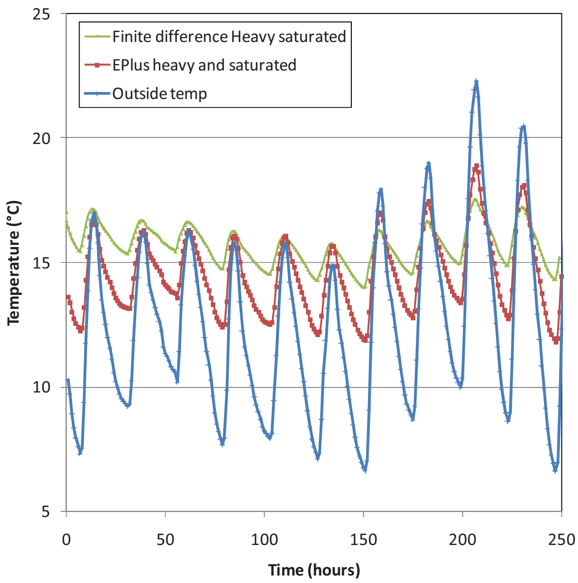

Figure 6 Comparison of labyrinth outlet temperature predicted by finite difference code and results from EnergyPlus Earth Tube module for the same soil and entry conditions.

Comparison with EnergyPlus Earth Tube module

The EnergyPlus simulation package incorporates a thermal model of an earth-to-air heat exchanger (or "earth tube) (EnergyPlus 2010). To determine how this model compared to the finite difference model described above, the current version of DesignBuilder (v2.4.2.015) was run with the EnergyPlus Earth Tube IDF module included. The results are shown in Figure 6 where it can be seen that EnergyPlus predicted a much larger swing in temperature at the outlet of the exchanger (and hence a lower heat transfer rate between air and earth). These results have also been plotted as outlet versus inlet temperatures (see Figure 7). It is interesting to note that the EnergyPlus program results show no phase lag between the inlet and outlet temperatures, i.e. the Energy Plus results lie on straight line for each given soil condition meaning that the outlet temperature of earth tube is the same irrespective of whether the inlet temperature is increasing or decreasing. This is counter-intuitive since one would expect a time lag which is correctly modelled by the finite difference method, i.e. those results form ellipses in figure 7. It would therefore appear that further work is needed to validate/confirm the methodology of the two modelling approaches.

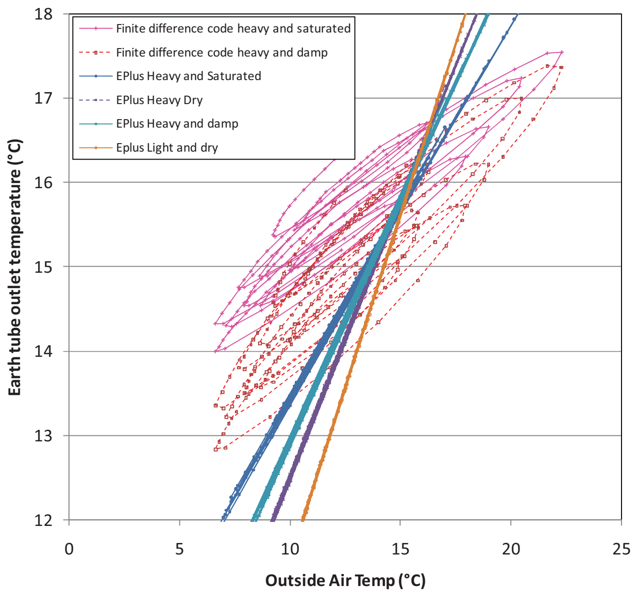

Figure 7 Plot of earth-to-air heat exchanger air outlet temperature vs. inlet temperature for various soil types and comparing finite difference and EnergyPlus module results.

ON-SITE RENEWABLE ENERGY GENERATION SYSTEMS

A key aim of the SBRC building project is to achieve Net Zero Energy operational status through strategy iii) above. The design of the renewable energy system was of course linked to both architectural constraints and local weather (solar and wind resources).

Photovoltaic Arrays

A number of photovoltaic (PV) arrays were planned for the SBRC building, including high efficiency mono- or poly-crystalline PV panels on the following surfaces: i) office roof at approx 15° to the horizontal; ii) high slope (~70º) square arrays north wall of high bay; iii) 35º slope (local latitude) long array north of high bay.

In addition, it was proposed that a section of the office roof be devoted to a PV-thermal (PVT) system supplying both electricity from PV panels and heated/cooled fresh air. The annual electrical output from the PV arrays was predicted to be of order 145MWh/year.

Horizontal Axis Wind Turbines

UOW have already installed one of two 5kW horizontal axis wind turbines (HAWTs) which will supply the SBRC with renewable energy. This first turbine is a prototype Aerogenesis device (Aerogenesis 2011) mounted on an 18m articulated tower, as shown in Figure 8.

Figure 8 Aerogenesis 5kW wind turbine. One of two to be used to power the SBRC building, mounted on 18m articulated towers.

The local wind resource has been estimated from two sources of data: a) from monthly mean data published on the Bureau of Meteorology website (BOM 2011); and from hourly historical wind data over the past fourteen years from the Bellambi weather station, which is located a similar distance from the coastline 4km north of the SBRC site (purchased from BOM). The average wind speeds likely to be found at the SBRC site are shown in Figure 9. From this monthly average data the approximate annual energy output from the two turbines was estimated to be 27,150kWh/year using the remote area power supply modelling software HOMER (Homer 2011). However, given that the SBRC building itself was expected to have a significant influence on the flowfield around the turbines a more detailed analysis was needed.

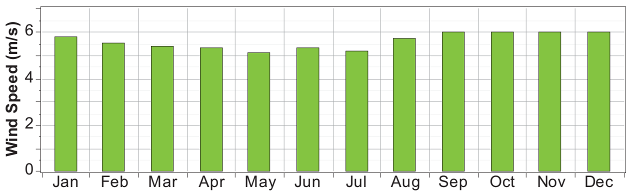

Figure 9 Monthly average wind speeds at the SBRC.

CFD simulation of wind resource and flow field

The location of a wind turbine in relation to buildings in the near vicinity is known to have a very strong effect on the performance of the turbine (Phillips, Blackmore et al. 2007). In an urban environment the effects of local obstacles can very greatly decrease annual energy output due to reductions in the local mean wind speed and increases in the local turbulence intensity. Of course the wind power available in a steady wind is proportional to the cube of wind speed.

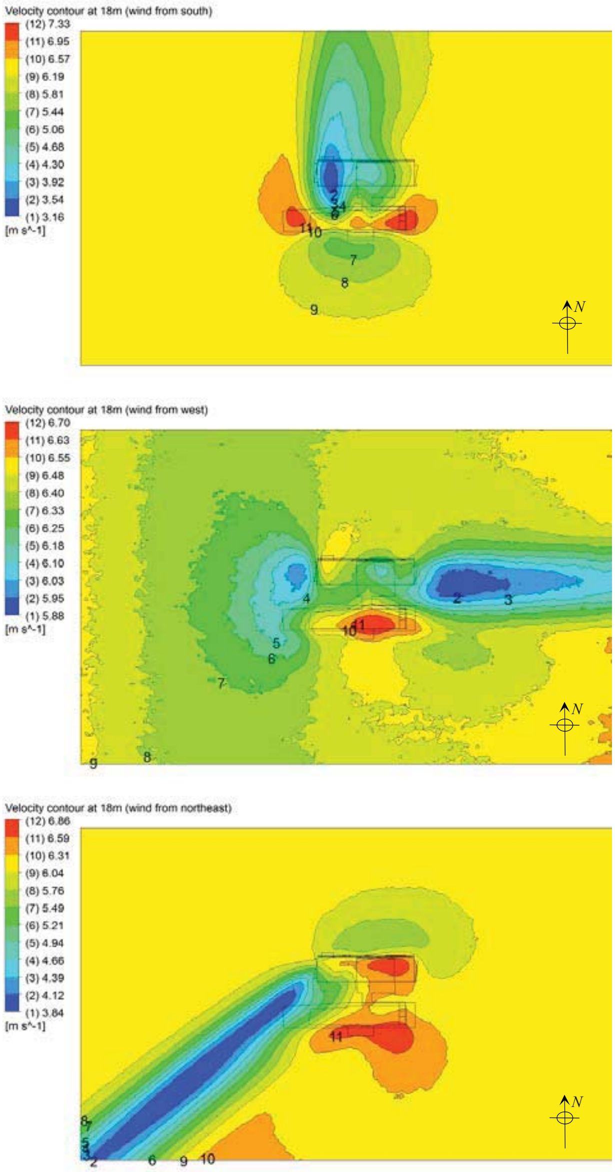

Figure 10 CFD results of wind speed at wind turbine hub elevation of 18m above ground (assuming upstream wind speed of ~6m/s at 10m).

To determine the effect of turbine location on the annual energy output a CFD analysis of the velocity field in the vicinity of the SBRC building has been carried out, as a function of wind direction using the ANSYS CFX package. The mean velocity profile as a function of height was specified at the upstream boundary of the computational domain. This was calculated assuming a wind shear index, α, that varied with the terrain roughness in that direction ($0.17 < \alpha < 0.25$). Results for the mean velocity at an elevation of 18m above ground are shown in Figure 10 for a range of wind directions.

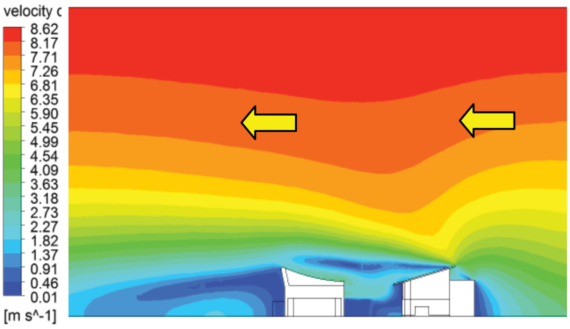

Figure 11 Illustration of wind speed over SBRC building for assessment of wind energy resource (wind from south).

Australian Bureau of Meteorology hourly wind speed data over the past 14 years from the nearby Bellambi weather station was then analysed to determine what fraction of time each year the wind blows from a given direction and at a given range of wind speed. The results are shown in Table 3. The wind speed and direction statistics were then combined with the eight wind speed maps for all the key wind directions (N, NE, E, SE, etc) to determine the annual mean wind energy density (kWh/m^2 swept area/year) at the 18m hub height of the proposed turbines as shown in Figure 13. Note that this methodology is only valid if the non-dimensional wind speed (local wind speed/freestream velocity) is independent of wind speed, which was found to be the case at 18m elevation in the present study.

Table 3 Summary of wind data averaged from hourly data over 14 years from Australian Bureau of Meteorology weather station Bellambi.

	Wind Direction								
Wind speed (m/s)	E	NE	N	NW	W	SW	S	SE	**Sum for speed**
1	0.76%	0.33%	0.31%	0.35%	0.45%	0.61%	1.46%	0.98%	**5.25%**
2	0.79%	0.35%	0.33%	0.31%	0.45%	0.70%	1.44%	1.19%	**5.56%**
3	2.27%	1.09%	1.03%	0.92%	1.20%	2.89%	4.06%	2.73%	**16.19%**
4	2.59%	1.52%	1.15%	1.12%	1.39%	4.28%	2.90%	1.75%	**16.70%**
5	2.34%	1.68%	0.81%	1.00%	1.61%	3.73%	1.62%	1.04%	**13.83%**
6	1.75%	1.64%	0.54%	0.89%	1.92%	2.42%	1.48%	0.64%	**11.28%**
7	1.05%	1.55%	0.31%	0.72%	2.10%	1.33%	1.16%	0.39%	**8.61%**
8	0.56%	1.32%	0.21%	0.56%	2.01%	0.84%	0.96%	0.27%	**6.72%**
9	0.28%	1.14%	0.15%	0.42%	1.64%	0.48%	0.54%	0.17%	**4.82%**
10	0.15%	0.88%	0.09%	0.26%	1.19%	0.26%	0.30%	0.14%	**3.27%**
11	0.08%	0.57%	0.07%	0.15%	0.75%	0.13%	0.18%	0.11%	**2.04%**
12	0.04%	0.32%	0.04%	0.09%	0.48%	0.07%	0.12%	0.08%	**1.24%**
13	0.02%	0.12%	0.02%	0.04%	0.32%	0.03%	0.08%	0.04%	**0.67%**
14	0.01%	0.04%	0.01%	0.03%	0.17%	0.03%	0.07%	0.03%	**0.38%**
15	0.00%	0.01%	0.00%	0.02%	0.09%	0.02%	0.04%	0.02%	**0.19%**
16	0.00%	0.00%	0.00%	0.01%	0.05%	0.01%	0.03%	0.02%	**0.12%**
17	0.00%	0.00%	0.00%	0.01%	0.01%	0.00%	0.01%	0.00%	**0.04%**
18	0.00%	0.00%	0.00%	0.01%	0.01%	0.00%	0.02%	0.02%	**0.06%**
19	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%	**0.03%**
20	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.01%**
21	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.01%**
22	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
23	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
24	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Sum for directio	**12.69%**	**12.56%**	**5.07%**	**6.90%**	**15.86%**	**17.82%**	**16.48%**	**9.64%**	

Finally the annual energy output from a single Aerogenesis wind turbine was determined by cross-multiplying the wind energy statistics, the wind velocity maps and the power output vs. wind speed characteristic of the turbines (Figure 12). The final contour plot is shown in Figure 14. It can be seen that the energy harvested by the turbine is relatively insensitive to position outside the immediate vicinity of the SBRC Building, largely because the top of the building is significantly lower than hub height. It appears that a gain of about 10.1MWh/year/turbine may be achievable (as compared to 14.1MWh/year/turbine predicted from the monthly weather data and Homer).

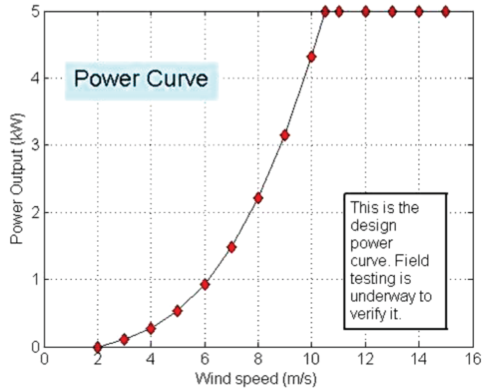

Figure 12 Aerogenesis 5kW wind turbine published power curve(Aerogenesis 2011) .

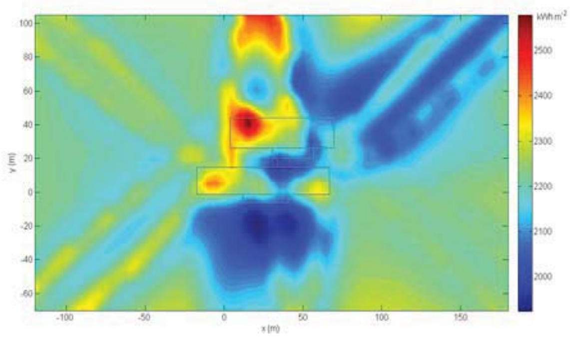

Figure 13 Annual wind energy density (kWh/m^2/year) at 18m elevation for the SBRC site using CFD modelling and wind speed and direction statistics.

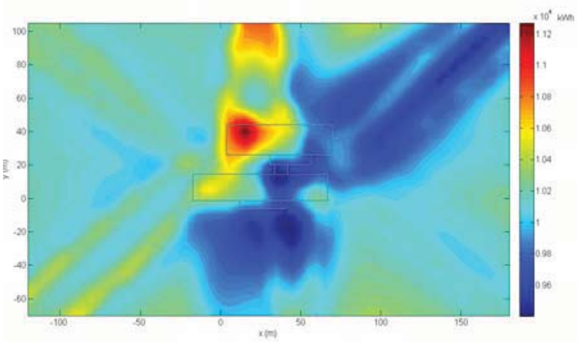

Figure 14 Annual energy output in kWh predicted for a single 5kW Aerogenesis turbine at 18m elevation for the SBRC site.

DISCUSSION AND RESULTS ANALYSIS

The preliminary energy analysis of the SBRC building has highlighted some of the challenges involved in the development of a net zero-energy commercial or educational building. In particular, close attention to aggressive reduction of IT loads is critical. This is generally not an easy goal to achieve as universities and other institutions often have very restrictive design specifications that do not allow for flexibility in the choice of IT hardware or operational and support systems.

As with every project, budget constraints limited the range of technical options adopted in the final design. The simulations above indicated that the earth-to-air heat exchanger proposed would at best give a heating/cooling effect of less than 10kW and thus this technology was not adopted for reasons of cost.

Detailed modelling of the influence of the local micro-climate and wind environment is an important part of the development of an accurate energy budget for a building using on-site wind generation. In the case of the SBRC building, a favourable wind resource (mean wind speed > 5.5m/s) appears to result in an energy harvest of approximately 10MWh/year from each 5kW wind turbine.

CONCLUSION

This paper has outlined some of the drivers that are currently influencing designers of low energy buildings with a long-term view to the achievement of net zero-energy or "nearly net zero-energy" buildings. The SBRC building has provided a useful case study through the modelling of a number strategies and options to minimise electricity demand and maximise on-site generation.

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