AUSZEH DESIGN: SOFTWARE FOR LOW-EMISSION AND ZERO-EMISSION HOUSE DESIGN IN AUSTRALIA

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ABSTRACT

A holistic strategy to significantly reduce carbon emissions in the residential housing sector will involve the design and delivery of new houses with low or zero emissions. This paper presents a new tool for the design of individual low-emission and zero-emission houses in Australia. Based on the engine of CSIRO's AccuRate house energy efficiency rating software but with new modules and capabilities, the AusZEH Design tool combines a whole house energy consumption tool with a supply-demand matching optimisation model. It deals with the technical and economic optimisation of the individual house energy demand and on-site renewable supply system. The tool enables evaluation of demand-reduction technologies and their integration given the building location, construction and occupancy scenarios.

INTRODUCTION

In 2005 to 2006, carbon emissions from Australian building operation contributed 23% (13% from the residential building sector and the remaining from the commercial building sector) to the total national CO2-e emissions (CIE, 2007). While the building sector is not the largest contributor to GHG emissions, it is one of the fastest-growing sources. Addressing energy use in buildings has been identified as one of the most cost-effective among many possible mitigation measures across different sectors (Levine et al., 2007).

There are a number of zero energy (emission) housing practices developed in some countries, which aim to significantly reduce GHG emissions from housing. Zero (energy) emission houses (ZEH) cannot be achieved solely through the improvement of individual building components (e.g. windows, appliances, heating and cooling equipment, lighting etc). It requires a revolutionary approach to building design and operation that can achieve substantial reductions in energy demand, coupled with a careful integration of on-site renewable energy supply. An affordable ZEH also requires cost optimisation of these technologies and systems. With the Building America research project, BEopt (Christensen et al., 2005) and EnergyGauge USA (http://www.energygauge.com, accessed April 2011) models have been developed by the National Renewable Energy Laboratory (NREL) and the Florida Solar Energy Centre, respectively. BEopt calls upon the DOE-2 and TRNSYS simulation engines and uses a sequential search technique to automate the process of identifying optimal building designs to approach zero net energy. EnergyGauge USA uses the building energy simulation software DOE-2 to simulate energy use and provides the combined evaluation of both the energy use and the economic and financial impacts of home energy-efficiency decision-making. Wang et. al. (2009) used EnergyPlus and TRNSYS 16 for zero energy house design in the UK: EnergyPlus simulations were applied to enable façade design studies considering building materials, window sizes and orientations, and TRNSYS was used to investigate the feasibility of ZEHs with renewable electricity, solar hot water system and energy efficient heating systems. These programs may be used for designing energy efficient buildings. However, occupancy patterns were not included.

In Australia, there are several advanced sustainable building design standards such as NABERS (http://www.nabers.com.au, accessed April 2011) and Green Star (http://www.gbca.org.au/green-star/, accessed April 2011). While these standards provide ranking criteria for evaluating energy efficiency in buildings, there are no specific strategies, design guidelines or tools available for the design of net zero emission buildings (ZEB). (Note that embodied energy/carbon emissions are not included in this paper.)

The Australian Zero-Emissions House (AusZEH) project (http://www.auszeh.org.au, accessed April 2011), which started in 2007, aims to develop and demonstrate technologies and innovative solutions to significantly reduce GHG emissions from the residential building sector. One of its objectives is to develop a tool for the design of individual zero emission houses in Australia. The AusZEH House Design Tool combines the total house energy consumption tool (based on an enhanced version of CSIRO's AccuRate (Delsante, 2005; Ren and Chen,

2010) with HOMER- a supply-demand matching optimisation model (NREL, 2007) from the US National Renewable Energy Laboratory. It deals with the technical and economic optimisation of the individual house-renewable energy demand and supply system. The tool enables evaluation of demand-reduction technologies and their integration given the building location, construction and occupancy scenarios (e.g. a young family at home, a couple working full-time, etc).

The aim of this paper is to:

a) present the theoretical development and design of the AusZEH Design tool;
b) demonstrate its utility by the combined implementation of its energy consumption modules and the renewable energy supply analysis model; and
c) demonstrate the tool's ability to inform decisions about appliances, space heating and cooling, lighting and hot water systems.

METHODOLOGY

Tools that aim to achieve an affordable (e.g., cost effective) ZEH design must have a powerful search engine to automate the cost effective process by simultaneously identifying optimal building designs, energy efficient appliances and optimal on-site renewable energy supply system designs. A practical and effective way to simplify the process is to separate it into two parts: reducing demand and optimizing the design of the renewable supply. First, the energy requirement is reduced through cost-effective building designs and energy efficient appliances. Then, the on-site renewable energy supply system is optimised for the corresponding energy requirement. This strategy is used for the development of this tool.

The AusZEH Design tool builds on the AccuRate simulation engine to enable façade optimization, taking into account building construction materials, elements and orientations with the actual choice of space heating and cooling system, lighting, water heating and appliances. It uses HOMER for investigating the feasibility of renewable energy systems for ZEH. Figure 1 gives an overview of the structure of the tool, which has three basic components: a simulation manager, an energy demand simulation model, and renewable energy supply model.

The simulation manager controls the entire simulation process, which instructs simulation modules to take actions such as simulate, record, report, or launch the renewable supply simulation.

The energy demand simulation model was developed for assessing household energy consumption for space heating and cooling, lighting, water heating and appliances, which are described as following.

Energy consumption for space heating and cooling

The total energy demand of a household includes space heating and cooling, lighting, hot water and appliances. The heating and cooling energy requirements were projected using AccuRate – the residential house energy rating software used in Australia. The AccuRate software was developed by coupling a frequency response building thermal model (Walsh and Delsante, 1983) and a multi-zone ventilation model (Ren and Chen, 2010) for energy requirement calculation of residential buildings. Taking into account the local climate and building fabrics, AccuRate's simulation engine automatically switches the building operation between mechanical air conditioning and natural ventilation operation when natural ventilation satisfies thermal comfort and calculates hourly heating and cooling (H/C) energy requirement over a period of one year. To achieve thermal comfort, the heating and cooling thermostat settings used in AccuRate for house energy rating are based on the Protocol for House Energy Rating Software published by Australian Building Codes Board (ABCB, 2006). Based on the annual total H/C energy requirement, AccuRate assigns a star rating between 0 and 10 star to the residential building for the specified climate zone, which is defined by the Australian Nationwide House Energy Rating Scheme (NatHERS). The higher the star rating is, the more energy efficient the building is. Currently, 5-Star represents the most new house designs since 2005 (DEWHA, 2008).

In this study, to consider occupant behaviours and occupancy patterns, the enhanced version of AccuRate allows users to change the thermal settings, which include heating and cooling schedules and thermostat settings, by considering occupant behaviours and occupancy patterns, which are discussed in sub-section Occupancy Profile.

AccuRate contains 69 Typical Meteorological Year (TMY) weather files linked to climate zones that cover all Australian states and territories. The AccuRate engine was tested satisfactorily against BESTEST (Delsante, 2004).

Projection of energy consumption for lighting, water heating and other household appliances

The energy consumption for lighting, water heating and other household appliances are not included in AccuRate for energy star rating. Thus, the modules for the energy consumption of these systems and appliances were developed.

The energy consumption for lighting was estimated as follows (Yao and Steemers, 2005):

$$E = \left(\frac{I_{mean}}{L_{eff}}\right) \times h \times A_{floor} \times \left(\frac{N_p}{N_r}\right) \Big/ 1000 \qquad (1)$$

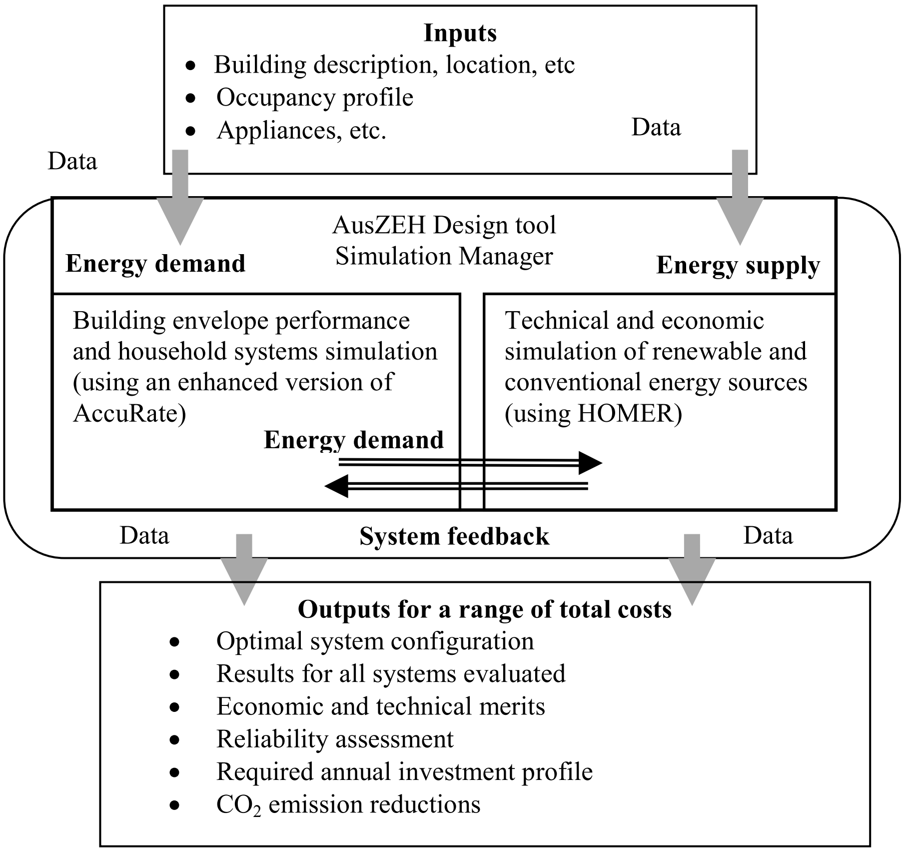

Figure 1 Structure of the AusZEH Design tool

where E is the daily electric lighting energy consumption (kWh/day); I_{mean} the average luminance level required (150 lum/m^2 for residential buildings); h the hours of artificial lighting on for a day; L_{eff} the luminance efficacy (lum/W); A_{floor} the house floor area (m^2); N_p the number of occupants; N_r the number of rooms in the house.

The energy consumption for hot water is calculated using the same approach as WHAT HO! (Burgess and Cogan, 2008) – a water heating assessment tool developed by BRANZ Ltd for the former Australian Department of the Environment, Water, Heritage and the Arts (DEWHA). It calculates the energy consumption and GHG emissions for individual household up to three separate water heating systems, including solar hot water system.

Based on published data of energy usage by household appliances in Australia, a new model for assessing energy consumption of household appliances was developed. In general, the annual energy consumption of an appliance can be estimated as:

$$E = (h_a \times W_a + h_{sby} \times W_{sby} + h_{off} \times W_{off})/1000 \qquad (2)$$

where E is the annual electric appliance energy consumption (kWh/year); W_a, W_{sby} and W_{off} are the power (Watts) in active, standby and off modes, respectively, which can be referenced to the appliance information given by the manufacturers; h_a, h_{sby} and h_{off} are the time (hours) spent in active, standby and off modes, respectively. These are important parameters for calculations of energy consumption and the typical data can be obtained from the report of Energy Use in the Australian Residential Sector (DEWHA, 2008).

Occupancy profile

To assess energy consumption for space heating and cooling, hot water, and some other appliances, the two most critical user behaviour factors are the number of occupants and the actual hours of occupancy of the dwelling. According to the Australian Bureau of Statistics (ABS) survey titled *How Australians use their time* (Time Use Survey) ABS 4153 conducted in both 1992 and 1997, three occupancy profiles were specified in the DEWHA report (DEWHA, 2008) as follows:

- Scenario 1: Unoccupied period is from 09:00 to 17:00. All occupants in the house have full-time jobs.
- Scenario 2: The house is occupied all the time. This type of household may have a young child to look after or the occupants may be retired.
- Scenario 3: Unoccupied period is from 17:00 to 20:00. This profile is most prevalent on a Saturday evening.

In this study, in addition to the three profiles above, other four profiles are proposed to represent potential household occupancy profiles in Australia:

- Scenario 4: Unoccupied period is from 09:00 to 13:00. One of the occupants in this type of household may have a part-time job in the morning session.
- Scenario 5: Unoccupied period is from 13:00 to 17:00. One of the occupants in this type of household may have a part-time job in the afternoon session.
- Scenario 6: Unoccupied period is from 09:00 to 15:30. This household may have a child to look after when school is finished.
- Scenario 7: User defining mode. This was designed to allow the users to define their own occupancy patterns.

The energy consumption pattern depends primarily on the occupied period. For example, when the house is not occupied, space heating/cooling system, lighting, and most of the appliances may not be used. In the daily appliance load profile, the house uses little power (most appliances in stand by) during the sleeping hours. In the evening, houses may use relatively more energy for cooking, dishwashing, television, computers, etc.

Renewable energy supply model

After running the enhanced version of AccuRate, an *xml* file is produced which includes local resources (solar radiation and wind speed) and an energy demand profiles for the household and for each module (space heating and cooling, lighting, appliances and hot water). As the input file of the renewable energy supply model, this file will be transferred into HOMER for optimization and sensitivity analysis of the renewable system design.

HOMER simulates the hourly operation of a system by comparing the electric and thermal demand in the hour to the energy that the system can supply in that hour, and then determines whether it can meet the electric and thermal demand under conditions that you specify. It also estimates the cost of installing and operating the system over the lifetime of the project. For the ZEH design, HOMER (NREL, 2007) can model grid-connected and off-grid renewable systems to match the electric and thermal energy profiles output from the enhanced version of the AccuRate engine. HOMER's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability and other variables (NREL, 2007).

APPLICATION AND EVALUATION OF THE AUSZEH DESIGN TOOL

Case study

To illustrate the process involved in achieving a ZEH, a conventional single-storey house with a floor area of 160 m^2 (and a conditioned floor area of 140 m^2) was modelled by the AusZEH Design tool. The house has four bedrooms (master bedroom with ensuite and WIR), a kitchen/family area, a living room, a laundry, a separate bathroom, a toilet, and entry hall. A couple with a baby and a school-aged child live in the house, which is located in Melbourne, Australia.

Two house scenarios for the total energy demand were modelled to illustrate the demand-side optimisation process that must be undertaken before supply via renewable energy is considered:

- **Average**: this represents a modest-performance house that could be built today: the envelope energy rating just achieves the minimum 5-star required in Melbourne; appliances with an average energy rating are used (where star ratings are available); the coefficient of performance (COP) of the central electric heat pump used is assumed to be 2.38; a ducted central cooling system (COP=2.5) is applied for space cooling; an electric storage hot water system is used for heating water; and general lighting (incandescent GLS) is used.
- **Best**: this represents a building envelope with 8 star energy rating, and with high energy performance systems and appliances: energy saving appliances are used (20% energy saving compared with the average appliances); the COP of the central electric heat pump used for heating and cooling is assumed to be 5.0; a solar hot water system boosted with electricity is used for heating water; and energy saving lighting (compact fluorescent – integrated ballast) is used. In average, a medium size 'Best' house will consume around 4300 kWh/ year in Australia (Delsante et. al., 2007).

While it would be possible to further increase the star rating of the house, the differences in heating and cooling energy between 8 and 10 stars (the maximum possible) are relatively small, while the cost to achieve higher star rating increases significantly.

A five-star energy rated house (the minimum requirements of the Building Code of Australia, enacted July 2004 in Victoria, Australia) now reflects typical practice in the Victorian domestic housing market. Typical construction properties for houses in Melbourne are listed in Table 1. Melbourne is a heating-dominated region and house orientation (indicated by large area window facing orientation) is usually north-facing to gain as much solar heat as possible during winter. Consequently, house orientation remains north-facing in the following discussions.

A range of construction options that achieve high star ratings were investigated in this case study, including: insulation of walls, ceilings and floors; windows (including window energy performance: U value and SHGC – Solar Heat Gain Coefficient);

Table 1 Five-star house construction properties in Melbourne

Building Elements	Material	U value
External wall	1. Brick work: generic pressed clay brick (typical density) 2. Air gap vertical 31-65 mm (40 nominal) unventilated non-reflective 3. Glass fibre batt: R1.0 4. Plaster board: 10 mm	0.67 W/m^2K
Window	Generic: Timber/uPVC single-glazed 3 mm clear glass; Window to Wall Ratio (WWR) = 0.15; Gaps around the window frame: medium	U = 5.75 W/m^2K SHGC = 0.69
Roof	Light colourbond	6.29 W/m^2K
Ceiling	13 mm plasterboard + R1.5 bulk insulation	0.58 W/m^2K
Floor	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic tiles/bare	1.53 W/m^2K 4.25 W/m^2K
Internal wall	Plasterboard on studs	2.28 W/m^2K
Door	50 mm timber (solid)	2.12 W/m^2K

Table 2 Eight-star house construction properties in Melbourne

Building Elements	Material	U value
External wall	1.Brick work: generic pressed clay brick (typical density) 2. Air gap vertical 31-65 mm (40 nominal)unventilated non reflective 3. Glass fibre batt: R4.0 4. Plaster board: 10 mm	0.2 W/m^2K
Window	Cedar awing double glazed 4 mm clear glass/12 argon gap/4 mm clear glass advantage low-E; WWR = 0.3; Gaps around the window frame: medium	U = 1.73 W/m^2K SHGC = 0.58
Roof	Dark colourbond	6.29 W/m^2K
Ceiling	13 mm plasterboard + R4.0 bulk insulation	0.24 W/m^2K
Floor	Concrete slab 100 mm: carpet/bare +R2.0 Concrete slab 100 mm: ceramic tiles/bare + R2.0	0.38 W/m^2K 0.45 W/m^2K
Internal wall	Plasterboard on studs	2.28 W/m^2K
Door	50 mm timber (solid)	2.12 W/m^2K

window to wall ratios (WWR); roof colour; and house air leakage. The evaluated result of the improved construction properties for the house to achieve 8 stars was shown in Table 2. As shown in Tables 1 and 2, to achieve 8 stars, the insulation of the external wall needs to be increased from R1.0 of the 5 star house to R4.0, the ceiling from R1.5 to R4.0 and the floor be insulated with R2.0. The single glazed windows need to be upgraded to double glazed low-E with 12mm argon gap, and the WWR from 0.15 to 0.3. The roof colour was improved from light to dark.

The energy consumption profiles for the houses ‘Average’ and ‘Best’ are shown in Figure 2. Compared to the current house (‘Average’), the ‘Best’ house can save near 60% energy. The largest part of the saving is space heating (87%), followed

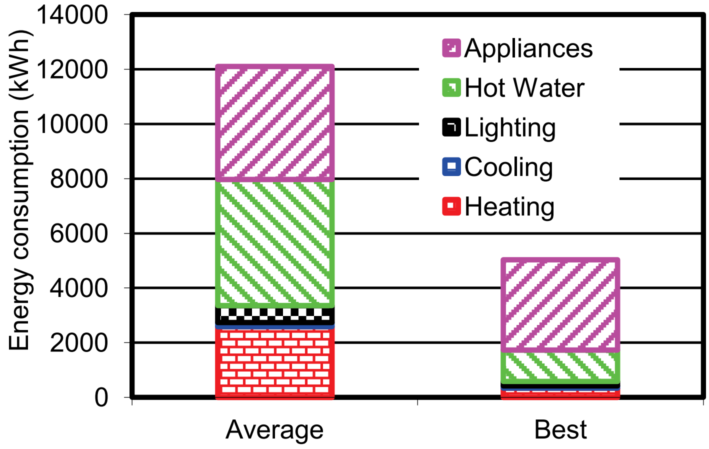

Figure 2 Energy consumption for the ‘Average’ and ‘Best’ houses

Table 3 The sizes and costs of the renewable systems required for the two building scenarios to achieve ZEHs

	PV (kW)	Convertor (kW)	Initial Capital (Aus $)
Average	12	6	47,085
Best	5	3	19,844

by solar hot water (75%), lighting (73%), cooling (47%), and appliances (20%). The total energy consumption of the ‘best’ house is dominated by the appliances (66%).

To achieve ZEHs for the above two scenarios, the sizes and costs of the PV systems and convertors are shown in Table 3 (for renewable resources, only PV was considered and the houses were allowed to link to the grid). The results are expected that the reductions of the PV size and convertor size, and the initial capital are about 58% for the Best scenario compared with the Average scenario, which are consistent to the reduction of the total energy consumption between the Best and the Average houses.

CONCLUSIONS

The development and capability of AusZEH Design has been presented. It is an integrated prototype software tool that combines the total household energy consumption with the on-site renewable energy supply optimisation software HOMER. The capability of AccuRate was extended from simulating space heating and cooling loads to predict the total house energy consumption, including space heating, space cooling, lighting, hot water and appliances. These were then combined or linked with the selection of a cost-optimised renewable energy supply system. With this powerful and practical combination of features within a single tool, AusZEH Design can be used for quick and cost-effective designs of low-emission houses and ZEHs.

The capability within AusZEH Design to predict hourly individual residential building energy consumption could be useful for predicting local and/or area-wide peak demand, and aid in electric network management.

SOFTWARE

Figure 3 is the screen snapshot of the main user interface of the tool, which includes inputs for building components (constructs, zones, elements, shading and ventilation), occupancy patterns (number and scenarios), and five modules (hot water, space heating, lighting, appliances, cooling), and outputs for total energy consumption and carbon emissions, and each modules.

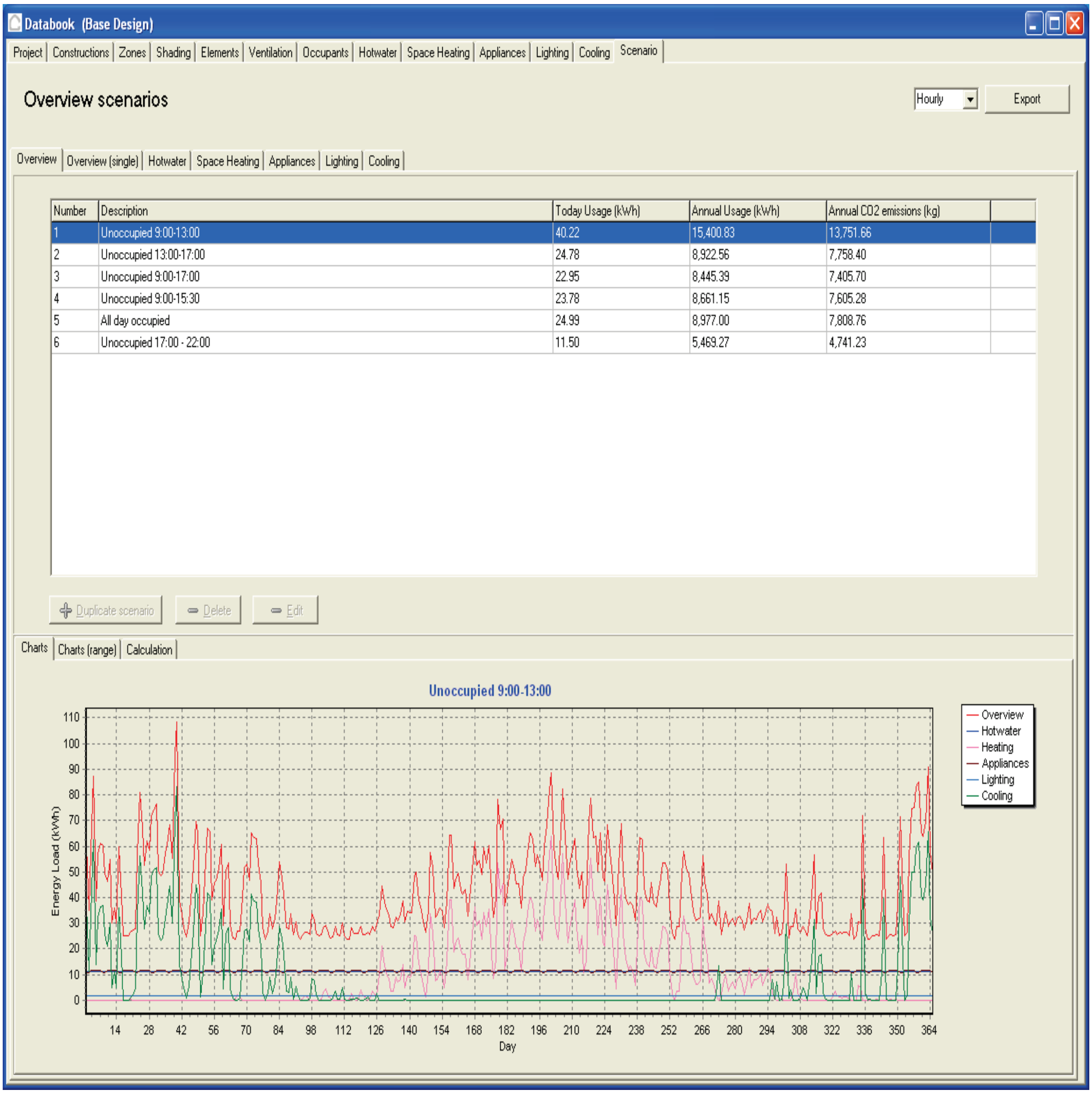

Figure 3 Screen snapshot of the main user interface of the AusZEH design tool

Future work

The AusZEH Design tool was used to design and construct the AusZEH Demo House in Laurimar, North of Melbourne and launched in April 2010 (http://www.auszeh.org.au). Tenants have moved into the house in early 2011 and performance monitoring and behavioural studies have commenced, and will run for at least a year. The monitored data will be used to evaluate the tool.

REFERENCES

ABCB (Australian Building Codes Board), 2006. Protocol for house energy rating software. Available from http://www.abcb.gov.au [accessed in April 2011].

Burgess, J., Cogan, D. 2008. A water heating rating tool for domestic construction in New Zealand and Australia. BRANZ Ltd report EC1475, submitted to EECA (Energy Efficiency and Conservation Authority).

Christensen, C., Horowitz, S., Givler, T., Barker, G. 2005. BEOPT: Software for identifying optimal building designs on the path to zero net energy. Paper presented in ISES Solar World Congress, August 6-12, 2005, Orlando, Florida, USA.

CIE (Centre for International Economics), 2007. Capitalising on the building sector's potential to lessen the costs of a broad based GHG emissions cut, research report prepared for ASBEC Climate Change Task Group, available at http://www.TheCIE.com.au, accessed April 2011.

Delsante, A. 2004. A validation of the AccuRate simulation engine using BESTEST. Report for the Australian Greenhouse Office, CMIT -2004-152.

Delsante, A. 2005. Is the new generation of building energy rating software up to the task? – A review of AccuRate. Paper presented in ABCB Conference 'Building Australia's Future 2005', 11–15 September 2005, Surfers Paradise, Australia.

Delsante, A., Foliente, G., Ren, Z., Tu, T., Stephen, W. 2007. Towards zero emission housing in Australia – A RD&D Roadmap. CSIRO report, USP2007/20.

DEWHA (Department of the Environment, Water, Heritage and the Arts), 2008. Energy use in the Australian residential sector 1986-2020. Available from: http://www.environment.gov.au [accessed in April 2011].

Levine, M., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G., Mongameli, M. A., Mirasgedis, S., Novikova, A., Rilling, J., Yoshino, H. 2007. Residential and commercial buildings. In Climate Change 2007*:* Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

New South Wales Department of Environment, Climate Change and Water, NABERS- the National Australian Built Environment Rating System, available at http://www.nabers.com.au; 2008.

Ren, Z., Chen, D. 2010. Enhanced air flow modelling for AccuRate – A nationwide house energy rating tool in Australia. Building and Environment, 45: 1276-1286.

The Florida Solar Energy Centre, EnergyGauge – Energy and economic analysis software, available at http://www.energygauge.com; 2006.

The Green Building Council of Australia, Green Star, available at http://www.gbca.org.au/green-star; 2006.

USA National Renewable Energy Laboratory, HOMER- Analysis of micropower system options, available at http://www.nrel.gov/homer; 2007.

Walsh, P.J., Delsante, A.E. 1983. Calculation of the thermal behaviour of multi-zone buildings. Energy and Buildings, 5:231–42

Wang, L., Gwilliam, J., Jones P. 2009. Case study of zero energy house design in UK, Energy and Buildings, 41:215-1222.

Yao, R, Steemers, K. 2005. A method of formulating energy load profile for domestic buildings in the UK. Energy and Buildings, 37: 663-671.