ILL Request

Item 1 of 1

ILL no	3347531 / 3347530
Status Change Date	16 Jul 2008
Title	Australasian journal of environmental management.
Author	Environment Institute of Australia and New Zealand.
Publisher	Environment Institute of Australia and New Zealand
Place of publication	Melbourne, Vic.
ISSN	1448-6563
Call Number	Serial QH77 .A8 Aus
Volume/Issue	13(4)
Volume/Issue date of publication	2006
Author of Paper	ghosh & vale
Title of Paper	The Potential for Solar Energy Use in a New Zealand Residential Neighbourhood: A Case Study Considering the Effect on CO2 Emissions and the Possible Benefits of Changing Roof Form
Pagination	216-225
Verification source	National Bibliographic Database/VOYAGER

Requester Symbol	NLNZ:LIPL
Requester Name	Landcare Research New Zealand Ltd Library
Material Type	Serial
Service Level	Normal
Service Type 1	Copy non returnable
Media Type 1	Photocopy
Status	In Process
Authorisation Status	To be Acknowledged
Copyright Text	This copy request is for the private study or research of the above user, or complies with s54 or s55 of the Copyright Act 1994
Copyright Subtype	NZ copyright requirements
Service Level	Normal
Expiry Type	Calc From Expiry Days
Expiry Date	24 Jul 2008
Requested Delivery Method	Electronic Mail (DocStore)
Req. Payment Status	Charter
Retry	No
Max Cost	14.00
Currency	New Zealand Dollar
Payment Provided	Yes

Delivery Address

Addressee	library@landcareresearch.co.nz; Prefer delivery by DocStore
Org, Dept, Bldg, etc.	Landcare Research New Zealand Ltd Library
PO Box	PO Box 40
Street	Gerald Street, Lincoln 7640
City	Lincoln
Region	Canterbury
Country	New Zealand
Post Code	7640

	Country Code	Area Code	Local Number	Extension
Facsimile	+64	03	321-9998	
Telephone	+64	03	321-9650	

E-mail docstore@natlib.govt.nz

The Potential for Solar Energy Use in a New Zealand Residential Neighbourhood: A Case Study Considering the Effect on CO_2 Emissions and the Possible Benefits of Changing Roof Form

*Sumita Ghosh and Robert Vale**

Solar energy, a renewable resource, is constantly replenished by natural processes and can be used by humans more or less indefinitely. This article quantifies the potential energy from solar hot water and photovoltaics that could be generated from the roofs of the built-up areas of an existing urban neighbourhood at Glen Innes, Auckland. It examines how solar energy can contribute towards total domestic energy requirements of households for two scenarios. It also explores possibilities of enhanced potential solar contributions with changes in roof configurations. The outcomes suggest that, with minimal changes in roof configuration, the residential rooftop potential in terms of percentage contributions of total domestic energy demands (except space conditioning) could increase from 73 to 82.5 per cent for a maximum utilization scenario. For a more realistic situation, taking account of available sizes and dimensions of solar equipment the energy contribution could be enhanced from 46 to 69 per cent. Assuming a continuation of the current trends in grid-scale local generation technologies, building roofs with correct orientations to allow the collection of solar energy makes significant contributions to reducing CO_2 emissions.

1 Introduction

New Zealand's commitment under the Kyoto Protocol is to reduce greenhouse gas emissions to 1990 average levels over the period 2008 to 2012, and to take financial responsibility for any emissions above this level if the target is not achieved (MfE 2005c: 9). This presents potential opportunities for the growth of renewable energy options such as solar and wind power. The New Zealand solar water heating industry has grown more that 40 per cent in the last 3 years, and Energy Efficiency and Conservation Authority (EECA) has anticipated that the development of distributed renewable generation will play an increasingly important role in future energy supply (MfE 2005a: 284; CAE and EECA 1996).

In 2004, New Zealand residential sector energy demand, with the exception of domestic transport, was 62.5 PJ (1 petajoule (PJ) = 10^{15} Joules) (MED 2005: 11), and this sector also consumed 34.3 per cent of the total electricity generated (MED 2006: 27). In total, New Zealand currently emits 8.1 t of CO_2/capita (MED 2006a: 33). Because of the high percentage of renewables in the generating mix, an average New Zealand household emits about 450 kg of CO_2/year from an average electricity use of 6700 kWh (kilowatt hours)/year and about 460 kg of CO_2/year from 2400 kWh/year of average gas use (NIWA Science 2006). Household Energy End-use Project (HEEP) studies over three locations - Auckland, Hamilton and Wellington - showed that hot water accounts for about 29 per cent of the total household energy use (Isaacs *et al.* 2003: ii). Space and water heating are the predominant uses of energy in New Zealand houses (EECA 2000b: 1).

Solar radiation can be utilized either as heat (e.g. solar hot water systems) or as electricity (through photovoltaic – PV systems). Solar water heating can be easily integrated with a building's existing water heating system. Considering variations in availability of solar energy in different locations, in New Zealand, a standard solar heating system could supply around 75 per cent in summer and between 25-45 per cent in winter of the total household water heating energy demands (EECA 2000a:1). The current cost of solar photovoltaic (small and large scales) in New Zealand is high, but it is estimated that it has very large cost reduction potential in the next 15 years (PCE 2005: 24). Distributed PV systems for electricity supply eliminate costs of transmission and distribution, create diverse resilient energy systems and could be deployed rapidly (Steven *et al.* 2005:11). Two major regions in the

**Sumita Ghosh and Robert Vale are with Built Environments, Environment and Society, Landcare Research, Auckland, New Zealand; Contact author's email: GhoshS@landcareresearch.co.nz.*

Table 1. Comparisons of National and International Solar Projects

Projects	Climatic data degree days, annual mean temperature	Descriptions	Solar technology and system	Actual solar performance
Skotteparken, Ballerup, Denmark	3400 heating degree days (base 18 °C); 7.8 °C	Apartments housing 100 families	Six solar heating systems 100 m² each; 6 m² solar panel/apartment; district heating network	382 kWh/m² including saved network losses; decrease in heat demand by 50% compared to conventional housing;
"Blixembosch 2" and "Driehoeksbos" Meerhoven, Eindhoven, Netherlands	2750 heating degree days (base 18 °C); 10.9 °C	New residential developments; "Blixembosch 2"(1600 dwellings) and "Driehoeksbos" (400 dwellings)	Two 2.75 m² solar collectors /standard roof; 476 installations in two sites; local district heating system	330 kg CO_2 reduction; decrease in heat demand by 50%;
South Wiggenhausen-Süd solar development, Friedrichshafen, Germany	3717 heating degree days (base 17 °C); 9.7 °C	570 houses	Individual modules for solar collectors range from 7.5 m² to 12.5 m²; 4300 m² of solar collectors	Will supply 50% of space heating and hot water requirements;
Hockerton Housing Project, Hockerton, Nottinghamshire, UK	2600 heating degree days (base 18 °C); 9.4 °C	Five single storey earth sheltered terrace dwellings and study centre on 10 ha site	7.65 kW array of photovoltaics plus 5.5 kW and 6 kW wind turbines, all grid-connected and passive solar gain from south-facing conservatories	The renewable energy system provides all the energy for the houses, which are designed to minimise energy demand.
2 Hauraki Road, Waiheke Island, Auckland, NZ	1150 heating degree days (base 18 °C) 15.3 °C	total floor area of 196 m²	315 L insulated solar hot water cylinder	supplying well over 90% of hot water demand
20 Karaka Road, Waiheke Island, Auckland, NZ	1150 heating degree days (base 18 °C) 15.3 °C	91m² three bedroom house	PV system 4.4 kW peak and consists of 36 panels (each 120 W at 12 V DC) in two strings	first year of operation the PV system generated 5300 kWh/year

Sources: European Commission, Directorate-General for Energy and Transport (2006) – http://www.managenergy.net/ indexes /I38.htm; IDMP (2006) http://idmp.entpe.fr/stations/NZL03 /NZL03 /html;European Green Building Forum (2001); http://www.hockertonhousingproject.org.uk/; Nottingham Weather Centre (2006); Vale and Vale (2006).

forefront of applied solar technology are Australia and Western Europe. Availability of solar radiation in New Zealand (1400-1500 kWh/m^2) is at par with Melbourne (1472.7 kWh/m^2) and above European levels (Germany 1002.5 kWh/m^2), thus making future prospects of solar technology in New Zealand very attractive (EECA 2001: 14; Solar Industries Association 2006: 2-3). 'Solarization', the concept of mass retrofitting of roof, wall and floor insulation, draught proofing and solar water heaters to existing buildings, could achieve large greenhouse gas reductions (Blakers 2006). An average house roof of 150 m^2 receives around 220 000 kWh/year, more than 20 to 30 times the house's total requirements. 'The total household rooftop area in New Zealand is exposed to primary solar energy that is equivalent to about twice the total national energy consumed' (EECA 2001: 10). National climate change policies focus on greenhouse gas emissions from major sources such as agriculture, electricity generation and road transport (MfE 2005b: 13). 'Solar thermal is often not included in national energy policy targets because it is a heat technology and can most successfully be implemented at the local level' (EECA and SIA 2002: 2).

This article focuses on quantifying the potential contribution of solar energy collected at the local scale from the roofs of an existing urban neighbourhood in Glen Innes, Auckland, selected as a case study site. The potential residential rooftop contributions towards total domestic energy requirements of households are calculated for two scenarios. This article also examines the possibilities of enhanced potential solar contributions for the hypothetical case with improved roof configurations. Carbon dioxide mitigations or savings that could be achieved are also calculated and compared.

2 National and international examples

In countries such as the United Kingdom, Germany, the Netherlands, Denmark and Ireland, there has been significant work on the potential of solar energy use in domestic purposes. Initiatives to enhance solar generation from roofs such as the 'Million Solar Roofs Initiative' in the United States (US Department of Energy 2005), '100,000 Roofs Programme' in Germany, and Japan's 'New Sunshine Programme' and '70,000 Roofs Programme' (Brown 2001:109; Jiménez 2004) indicate utilising roofs for solar energy collection and use is an important consideration internationally. Table 1 presents a comparison of some selected national and international examples.

Heating demand depends on the rate of heat loss from a building (related to the building fabric), and the temperature difference between the inside and outside of a building: the greater the temperature difference the more heat will be lost (Carbon Trust 2006). Heating degree days are a measure of severity and duration of cold weather, the colder the weather in a given month, the higher will be the degree day value (Carbon Trust 2006). Therefore, heating degree days provide a measure of the amount of heat needed in a given climate, the higher the value the greater the annual space heating demand of the house.

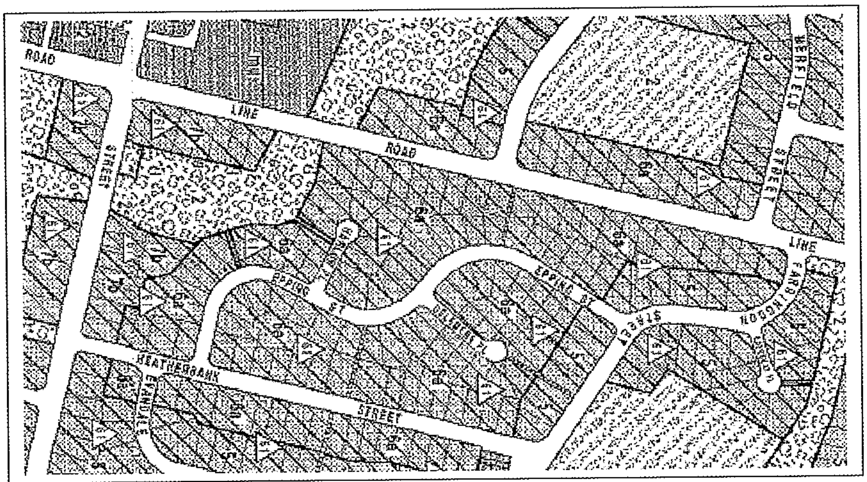

Figure 1. Glen Innes case study area Source: Auckland City Council (1999b)

3 Glen Innes – the case study site

Glen Innes is a low-density, low-rise, typical New Zealand suburb with detached large single houses in a medium-density zoning according to the Auckland District Plan Operative 1999. The styles of the buildings relate generally to the 1950s and are predominantly single storey houses. A significant part of the housing stock is state housing (government funded houses for rent). The case study site is bounded by Heatherbank Street towards the east, Line Road in the west, Farringdon Street towards the north and Taniwha Street in the south. Estimates based on New Zealand census data for 2001 show that the Glen Innes site has a population of 648, a calculated average household size of 3.8, and a total of 171 privately occupied dwellings (Statistics New Zealand 2001). Figure 1 presents the Glen Innes case study site.

3.1 'Auckland City: Growth Management Strategy' and 'Glen Innes into the future'

The *Auckland City: Growth Management Strategy* (Auckland City Council 2003), a vision for the future of the city, sets a broad strategic direction for urban development within the city to manage growth in a sustainable way. This growth management strategy also takes into account the policy outcomes of future regional growth according to the recommendations from the Auckland Regional Growth Strategy (Auckland City Council 2003).

In tandem with the decisions being made at the regional level about growth patterns, public transport development and land use, Auckland City has developed 'Auckland City: Growth Management Strategy (December 2003)' to provide a strategic framework to accommodate this expected growth on the Isthmus over the next 50 years (Auckland City Council 2003: 2).

This strategy has identified two areas of growth: areas of stability (which are not suitable for increased growth) and areas of change (where increased growth can be supported). The planning for growth in the latter is further classified into three priority centres: those such as Glen Innes where growth is already underway; those where growth will start as required; and those which would require infrastructure upgrades for growth uptake (Auckland City Council 2003: 3).

After extensive community consultation with the local community and stakeholders of Glen Innes, Auckland City has developed a livable community plan, 'Glen Innes into the future' (Auckland City Council, 2004c), which was adopted in 2004 by the Council. This provides a framework for managing growth and development in the area over the next 20 years. A key action identified within this strategy is to introduce the 'Residential 8' zoning that allows more medium- to-high-density housing such as town houses, terraced housing, and apartments that are in close walking distance of Glen Innes's town centre and public transport (Auckland City Council 2004a: 2; Auckland City Council 2004b). The key principles proposed to guide the future development of Glen Innes include: environmental protection; location of growth; integrated development; strong communities; urban design; economic development; employment; and funding (Auckland City Council 2004c).

3.2 Auckland City Council plan change in Glen Innes

Auckland City is undergoing a plan change process, 'plan change 61', in Glen Innes (Auckland City Council 2004a). The City Council publicly notified the plan change in 2005 and the hearing of submissions was held in June 2006. Under the Resource Management Act 1991 the Council has obligations and functions to undertake, in particular, evaluation of the proposed plan change before the notification of a change to a district plan. Auckland City Council's Section 32 Report analysed four scenarios for the proposed changes and considered public plan change as an effective method of achieving the Regional and the City Council's growth management objectives (Auckland City Council 2004a: 15). This public plan change 61 had proposed zoning changes for residential areas generally located within a five minute walk of the Glen Innes town centre and mainly fronting onto the arterial roads in the area – Apirana Avenue, Line Road, Taniwha Street, and Point England Road (Auckland City

Council 2004a: 3). Our case study site fulfills these locational criteria. Furthermore, the proposal to rezone the site from Residential 5, Residential 6a and Residential 7b to either Residential 8b or Residential 8a indicates the Council has identified this area as one which is most likely to accommodate significant future growth.

Residential 5 is a low density zoning with one to two storey detached houses with generous open spaces around the houses. Residential 6 is the most significant medium density residential zoning with a wider range of permitted activities allowing one residential dwelling unit per 375 m^2 of site area with a height limitation of 8 m and predominantly characterised by one or two storey developments. Residential 7b is a high density zoning characterised by developments up to and greater than four storeys with height limit of 12.5 m. The Residential 8a zone allows a residential density up to one unit per 150 m^2 and a maximum height of 11.0 m, while the Residential 8b zone permits a higher residential density up to one unit per 100 m^2 and a maximum height of 14.0 m (Auckland City Council 1999a, Part 7: A14 – A18). In spite of having a medium density zoning according to the Auckland District Plan Operative 1999, the case study site does not currently accommodate sufficient houses to become eligible as a medium-density housing area and is predominantly a low-density residential area. A summary of public submissions indicates many of the residents do not support rezoning options for Glen Innes (Auckland City Council 2004b).

3.3 Why has Glen Innes been selected?

According to the *Auckland City: Growth Management Strategy,* Glen Innes has been listed as one of the priority one centres for both residential growth and business development. Urban form changes are already occurring rapidly in this area.

Glen Innes is identified as a Priority 1 "area of change" in Auckland City's growth management strategy because it has the following characteristics:

- good access to Central Auckland and to Manukau by road and rail
- a growing population, which is expected to grow by about 3,000 people or 900 new homes within the next 20 years
- well established community and town centre
- availability of some vacant or underdeveloped residential and business sites
- natural features and open spaces (Auckland City Council 2004c: 7).

Apirana Avenue, a regional arterial road, and Taniwha Street, a district arterial road, go through Glen Innes in addition to the collector street, Line Road. Glen Innes is also located at a moderate distance from Auckland's central business district (CBD). The site is approximately 25-35 minutes ride by car and bus, 14 minutes by train, and is located at a radial distance of nine kilometres from the CBD. The town centre has an excellent combination of public transport (train route connecting the city and other suburbs of Auckland; bus terminal), shopping centre, business activity areas, open space areas, special purpose activity areas, and residential areas ranging from Residential 5 to Residential 8 surrounding all these activities. The forthcoming local urban form transformations in Glen Innes provide a useful research focus to understand such issues as local environmental sustainability in relation to various attributes, land uses, zoning, forms of urban development such as smart growth, transit oriented development (TOD), new urbanism characteristics, urban design and ecological qualities.

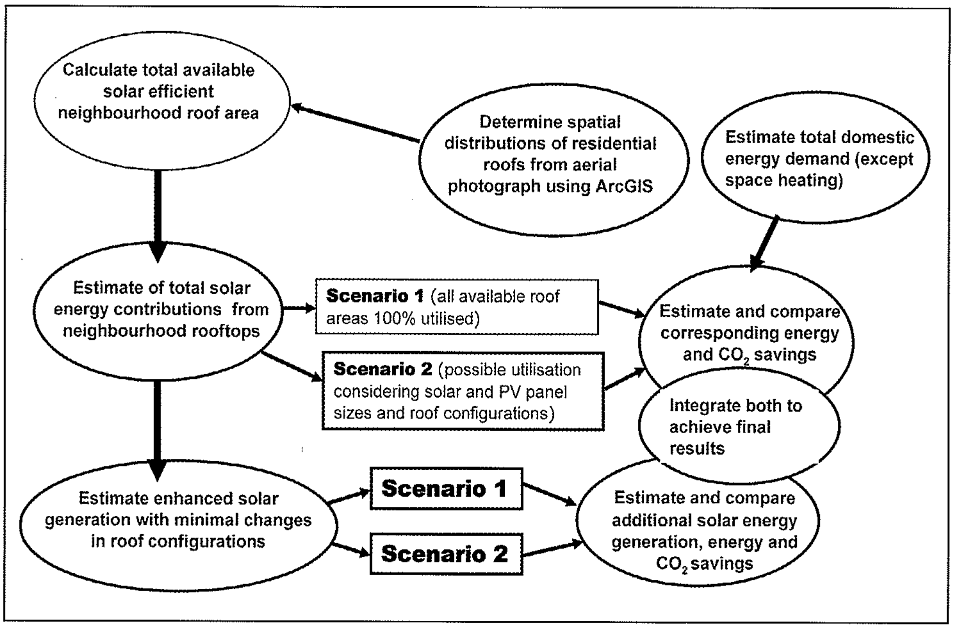

Figure 2. Methodology flow chart

Table 2. Existing demands of household energy use

Data HEEP, year 7	% Contributions	Existing demands (GJ/ annum)
Water heating	29.0%	2914
Space conditioning	22.0%	2210
Cooking	8%	804
Entertainment	3%	301
Lighting	11%	1105
Refrigeration	10%	1005
Others, unassigned and large miscellaneous	17%	1708
Total	-	10047

Source: HEEP, Year 7 (2003).

The future redevelopment provides an opportunity to incorporate more potential for sustainability.

4 Methodology

The complete methodology flow chart for the case study calculations is presented in Figure 2.

4.1 Existing domestic energy demand calculation

As a first component of the research discussed above, the total existing demands of household energy use in water heating, space heating, cooking, refrigeration, lighting, entertainment, etc. are separately estimated from the calculated data on per capita national requirements based on overall energy use from the Ministry of Economic Development data (MED 2005:11) for the Glen Innes case study area. BRANZ has been conducting the HEEP for last nine years. The HEEP study (Isaacs *et al.* 2003) suggests there is no statistically significant difference in average household energy use between HEEP sample houses in Auckland, Hamilton, Wellington and Christchurch considering electricity and natural gas by end use. This study included energy demand for space heating. Improved estimates of household appliance energy use have been prepared showing that over all these locations and considering electricity and gas household energy end use, hot water accounts for about 29 per cent, space conditioning 22 per cent, lighting about 11 per cent, refrigeration about 10 per cent, cooking about 8 per cent including range, entertainment 3 per cent, and others, unassigned and largely miscellaneous, about 17 per cent of the total (Issacs *et al.* 2003: ii.). Comparison of earlier data from EECA and Centre for Advanced Engineering (CAE) sources indicates water heating was 36 per cent and space heating was 38 per cent of total domestic energy use in 1995 for all types of energy including geothermal (CAE 1996: 48; EECA 2000c). Total domestic energy use on a national scale has risen from 52.9 PJ for the year 1995 (EECA 2000c, Table C7: 112) to 56.8PJ in 2001 (MED 2005: 11).

In the chosen case study area, water heating energy could be contributed largely by roof-mounted solar water heating panels. The energy generated by photovoltaic (PV) arrays mounted on the appropriate roof areas should be used for those functions that specifically require electricity (such as entertainment, lighting, and refrigeration), rather than using the electricity for space conditioning. Though cooking could be also done by gas, it has been assumed for the purpose of this study that 49 per cent of the energy requirements for household use (that is all energy demands except water heating and space conditioning) (Isaacs *et al.* 2003: ii), will be from electricity. Table 2 presents existing household energy demands calculated in different categories. Excluding space conditioning, in all other categories the total energy use of the Glen Innes case study area is 7837 GJ/year (1 gigajoule (GJ) = 10^9 Joules). Space heating is excluded from the analysis from this point because it does not need to be provided by electricity.

4.2 Potential on site solar energy generation based on current building roof orientations

4.2.1 Building roof areas and solar efficient roof areas estimation

In 2001, Rylatt *et al.* developed a GIS based solar energy planning tool taking into account key solar technologies: solar water heaters, photovoltaics and passive solar gain, for various residential dwelling types, age and building footprints (Rylatt *et al.* 2001: 579, 589).

In our research a neighbourhood scale spatial methodology, developed by Ghosh (2004), using aerial photographs was applied. In this methodology the total building roof areas of the Glen Innes case study area are calculated. The total site area is 15.5 ha and current density is 11 dwellings/ha which is low. The value of total building roof areas is equal to 2.3 ha and 15.1 per cent of the total site area. The total available solar efficient roof areas currently available are determined considering the slope of the roofs and roof orientations within 45° on either side of north using a geometric method of calculation (Breuer 1994). These solar efficient areas were drawn diagrammatically on the roof forms using ArcGIS and calculated spatially (Ghosh 2004). It is estimated that 0.61 ha or 6143 m² of the total roof area is currently solar efficient. Solar efficient roof areas that would be shaded by the existing trees are not included in the calculations. Figure 3 presents building roof areas and solar efficient roof areas of the Glen Innes case study site.

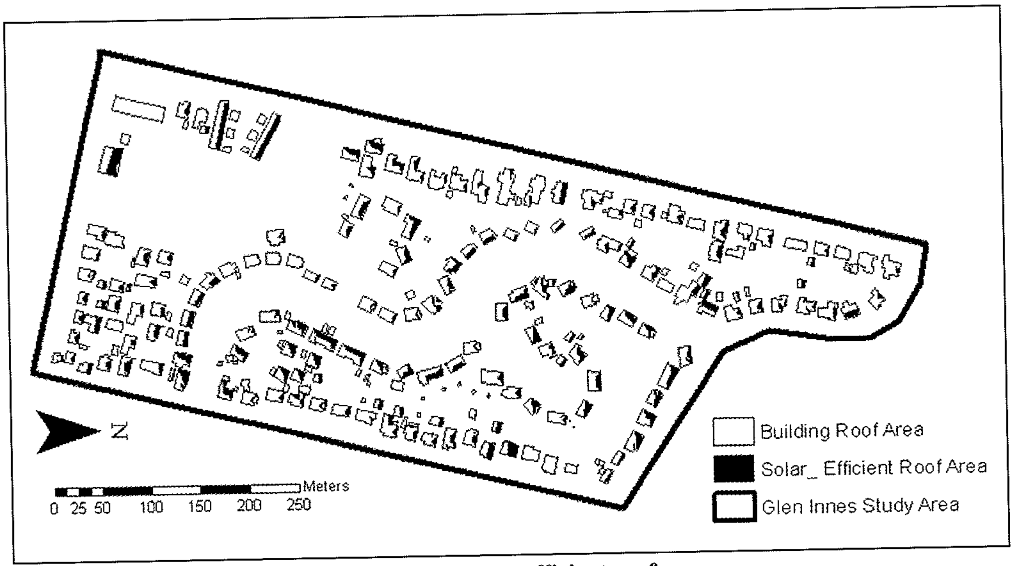

Figure 3. Glen Innes building roof area and solar efficient roof area

Different categories of building roof areas are present on the case study site, comprising large, medium and small houses, garages, stores and shades. Two categories, large roof areas ranging from 60 m^2 to above 200 m^2 and smaller roof areas below 60 m^2, are considered. Each category has four sub-categories. The analysis in Table 3 indicates that in the large roof areas category, the dominating group of building roof areas are between 100 and 149.99 m^2 and that 27.5 per cent of the total roof areas of these buildings are solar efficient. Roof areas below 20 m^2 dominate the smaller roof areas category, which may be garages and shades. Only 16.5 per cent of the total smaller roof areas are solar efficient. The orientation and locations of garages and shades in a traditional low density New Zealand neighbourhood probably are not given sufficient importance at the site planning stage. However, if rightly oriented, these small roof areas would be able to accommodate a 4 m^2 solar water heater, thus supplying all hot water demands of the households. Considering large and smaller roof areas, overall 26.2 per cent of the total building roof areas in the Glen Innes site are currently solar efficient.

4.2.2 Energy potential of current solar efficient roof areas

A recent study by the United Kingdom Department of Trade and Industry (2006) proposed that so-called 'micro-generation' (small-scale renewable energy systems such as solar panels on houses) could generate 30 to 40 per cent of the country's total electricity demand by 2050. Micro-generation can provide both hot water and electricity. For hot water provision, the Sola60TM H300 collector is designed to provide hot water for a family of six and has a 4.5 m^2 solar collector area and a 270 litre storage tank (CAE 1996: 186). It is therefore assumed that a 4 m^2 per household solar water heater area would be sufficient on average for all sizes of household and this would need to be placed on part of the solar efficient roof area (Ghosh 2004: 85). Energy generation from each 4 m^2 solar water heater is at the rate of 2200 kWh (CAE 1996: 186) or 7.92 GJ/year. 50 m^2 of photovoltaic modules can generate100 MJ /day, assuming 10 per cent efficiency in Auckland and 1 m^2 generates 2 MJ/day (Redshaw and Dawber 1996) or 0.73 GJ/year (Ghosh 2004: 126).

As the roof design of buildings could incorporate varying slopes and roof patterns, it is very important to determine how many of these solar efficient roof areas are useful. Solar water heaters or photovoltaic modules are generally in the form of rectangular panels, therefore, when placed on the roof of buildings they do not adequately cover all the solar efficient roof areas which have triangular edges, shorter lengths and different shapes. These various roof configurations affect the utilization of solar energy from solar efficient roof areas.

Table 3. Available solar efficient roof areas by size category

Category as per building roof area (m^2)	Numbers	Total building roof area	Total solar efficient roof area	Average %
Large roof areas				
60-99.99	24	1902	527	27.7
100-149.99	102	12462	3428	27.5
150-199.99	20	3412	877	25.7
Above 200	11	3150.7	902.7	28.6
TOTAL 1	**157**	**20927**	**5735**	**27.4**
Small roof areas				
1-19.99	32	379.4	43.7	11.5
20-29.99	29	705.47	52.2	7.4
30-49.99	23	485.02	104.21	21.5
50-59.99	9	907.7	207.68	22.9
TOTAL 2	**93**	**2477.5**	**407.8**	**16.5**
TOTAL (TOTAL 1 + TOTAL 2)	250	23404.3	6142.7	26.2

Table 4. Two scenarios on available solar roof area utilisations

Scenario 1		Scenario 2	
Total available solar efficient roof area (m2)	6143	Total available solar efficient roof area (m^2)	6143
Total area (m^2) of solar water heater required @ 4 m^2/ household	984	Total area (m^2) of solar water heater utilized @ 4 m^2 (2 no 1 m X 2 m solar panels) per household	634
Remaining area for photovoltaic (m^2)	5159	Area utilized for photovoltaic considering 58% use (m^2)	3195
Energy equivalent water heater (GJ/year)	1948	Energy equivalent water heater (GJ/year)	1255
Energy equivalent photovoltaic (GJ/year)	3766	Energy equivalent photovoltaic (GJ/year)	2332
Total onsite solar energy generation (GJ/year)	5714	Total onsite solar energy generation (GJ/year)	3588
Total onsite CO_2 emission savings (t /year)	1029	Total onsite CO_2 emission Savings (t/year)	646
% of existing demands except space conditioning category	73%	% of existing demands except space conditioning category	46%
Unused solar efficient roof area (m^2)	0	Unused solar efficient roof area (m^2)	2314
% of unused solar efficient roof area(m^2)	0	% of unused solar efficient roof area(m^2)	38
Energy equivalent unused solar efficient roof area	0	Energy equivalent unused solar efficient roof area	1689

Considering current available solar efficient roof areas, this article examines solar efficient roof utilization under two scenarios: full or 100 per cent utilization irrespective of roof configurations (scenario one) and partial utilization considering roof configurations (scenario two).

Under scenario one, all the solar efficient roof areas available are assumed to be utilized fully for solar hot water panels at the rate of 4 m^2/household, and the remaining area is allocated to photovoltaic modules. The corresponding energy equivalents in GJ/year and percentage of the total existing demands that could be provided in water heating and other categories (except space conditioning) are calculated. The results indicate that 5714 GJ/year and 73 per cent of the total existing demands (except space conditioning) could be provided by the currently available solar efficient roof area.

In scenario two, two solar water heating panels, 1 m by 2 m, equivalent to 4 m^2/household, are fitted on the solar efficient residential rooftops of the dwellings in Glen Innes using ArcGIS. Only 158 out of 171 dwellings could accommodate two solar water heater panels on their solar efficient roofs; one could accommodate one panel; and 12 buildings do not have appropriate solar orientations.

Similarly, photovoltaic modules of 0.6 m X 1.2 m were fitted on the area of solar efficient roofs remaining after placing solar hot water panels. This process was time-consuming and so was carried out for only 60 dwellings on the Glen Innes site. The realistic available areas of photovoltaic modules were compared with total available solar efficient roof areas for those 60 dwellings. The calculations show that these buildings realistically could use only 58 per cent of the total available solar efficient roof areas, and 42 per cent of the solar efficient roof areas would be lost due to inappropriate roof designs (mostly hips and valleys). The percentage value of 58 per cent obtained for photovoltaic modules in combination with solar water heater provisions was then applied to achieve overall results for the complete Glen Innes site. The corresponding energy equivalent in GJ/annum or percentage of the total existing demands that could be provided in water heating and other categories (except space conditioning) was then calculated.

The results indicate that 3588 GJ/year and 46 per cent of the total existing demands except space conditioning could be provided by solar energy collected from the existing rooftops. The results for scenarios one and two and corresponding CO_2 values of domestic energy savings were calculated and are presented in Table 4.

In New Zealand, the residential sector accounts for 10 per cent of the CO_2 emissions; directly for 1.6 per cent and indirectly for at least 8 per cent from thermal electricity generation (Issacs *et al.* 2003: i). The Ministry for Economic Development releases data on national electricity generation every quarter. Figure 4 highlights the rising dependence of New Zealanders on unsustainable sourcing of thermal electricity from fossil fuels (natural gas and coal).

Camilleri and Jaques (2001) have assumed that new macro-scale hydroelectricity projects are overburdened with public opposition and all new large-scale electrical capacity in New Zealand will therefore come from thermal sources at a greenhouse gas cost of 0.64 kg of equivalent CO_2 emissions/kWh of electricity (Camilleri and Jaques 2001: 25; Camilleri 2000: 60). The recent cancellation of Project Aqua (a large hydro-electricity scheme in the South Island) supports the idea that this assumption of no new macro-scale hydroelectricity generation is currently valid and that all new generation or any new reduction in usage will either increase or reduce the amount of thermal electricity demand in New Zealand, thus this figure of 0.64 kg of CO_2 /kWh (0.18 t/GJ) will be used in the CO_2 calculations here. Future changes in the mix of generating technologies for the national grid could change these CO_2 values, but the current trend is for thermal generation to increase (see Figure 4).

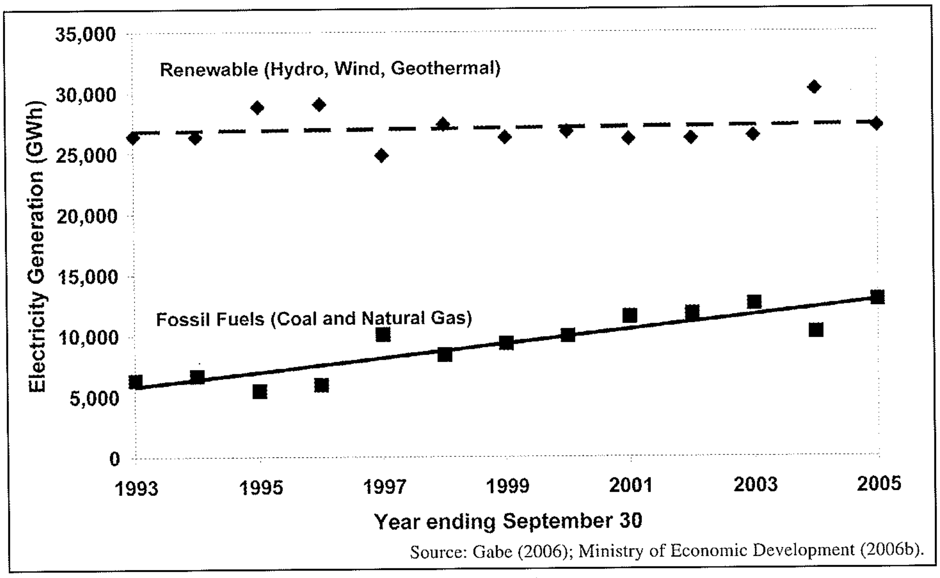

Figure 4. New Zealand electricity sourcing 1993-2005

4.3 Additional solar efficient roof generation

In Glen Innes, hip roof patterns currently predominate on single detached houses. Gable roofs provide more rectangular roof area in one plane compared with hip roofs, and could provide an increase in useful solar efficient roof area. (A gable roof is formed of two rectangular sloping planes that meet at the ridge. The roof is enclosed at either end by triangular vertical walls which are the gables. Each plane of the roof is a rectangle. A gable roof therefore has vertical ends, but a hip roof has sloping ends as well as sloping planes on both sides of the roof.)

Considering only minimal changes to roof configuration, such as using a gable end roof rather than a hip roof, the additional solar efficient roof area that could be generated was calculated. The outcomes suggest that for the maximum use (scenario one) of available solar efficient roof area, the residential rooftop potential could increase from 73 per cent to 82.5 per cent in terms of percentage contributions of total domestic demands (except space conditioning). For a more realistic situation (scenario two) this use could be enhanced from 46 per cent to 69 per cent with minimal changes in existing roof configurations for the selected case study site. Solar energy generation from minimal changes in roof configurations will save 1164 tonnes of CO_2 from Glen Innes per year in scenario one and 901 t of CO_2 from Glen Innes per year in scenario two.

Table 5. Additional solar efficient roof generation assuming gable roofs

Total additional available solar efficient roof area (m2)	1034
Scenario 1	
Assuming these additional solar efficient areas for photovoltaics & 100% use, energy output of photovoltaics (GJ/year)	755
Total onsite solar energy generation (GJ/year) (scenario 1+ additional)	6469
Total onsite CO_2 emission savings (t/year) (scenario 1+ additional)	1164
% of existing demands except space conditioning category	82.5%
Scenario 2	
Total additional area (m²) utilized that was lost in scenario 2 first version	2314
Grand total of the above two areas (scenario 2+ additional)	3348
Assuming this area is for photovoltaics & 58% use, energy output from photovoltaics (GJ/year)	1418
Total onsite solar energy generation (GJ/year) (scenario 2+ additional)	5005
Total onsite CO_2 emission savings (t/year) (scenario 2+ additional)	901
% of existing demands except space conditioning category	69%

5 Conclusions

At local scale, roof forms and orientations of buildings have a considerable impact on potential solar energy generation. This study establishes that correctly designed (i.e. rectangular) roof forms are able to enhance solar energy generation from roofs, allowing appropriate solar hot water and photovoltaic panel installations with minimal change. It is recommended that provision for the future installation of solar panels should be included at the conceptual stage of roof designs in any new individual buildings or large scale developments in Glen Innes. Energy retrofitting of traditional New Zealand suburbs would require changes in the roof forms such as from hip roofs to gable end roofs as rectangular roof planes could conveniently accommodate larger areas of photovoltaic arrays. Building such solar roofs can make a significant contribution to generating energy on site, with the potential to provide up to 80 per cent of household electricity demand in the case study site, and can also reduce production of CO_2 emissions. The CO_2 reduction of about 900 tonnes for the case study area represents 1.4 t/person. If this strategy was adopted for all residential areas it would deliver a significant reduction of 17 per cent of New Zealand's total CO_2 emissions.

Policy will be needed to undertake local scale planning and implementation through formulation of mandatory roof design guides applicable for different urban forms considering roofs as potential sites for the generation of onsite renewable energy. Different urban forms have varying on site potential to be sustainable (Ghosh and Vale 2006; Ghosh *et al.* 2006). For example, most of the attached terraced houses could be designed with orientations towards north in high density developments; while detached houses in low density traditional neighbourhoods would require consideration of each house's orientation. Incentives could be provided by central or local government to promote use of solar hot water and photovoltaic modules on roofs. The social barriers and economic calculations for the uptake of solar technologies have not been included in this study. Future research should undertake studies of these dimensions to present an integrated research focus on renewable solar energy generation from residential roofs as part of the move to design more self-sufficient neighborhoods.

6 Acknowledgements

The authors would like to acknowledge the support of the FRST funded 'Learning Sustainability' programme involving Landcare Research in collaboration with Opus International Consultants Ltd and the University of Auckland. They would also like to thank the referees for their comments and suggestions.

7 References

Auckland City Council. 1999a. *Part 7 - Residential Activity, City of Auckland.* District Plan, Isthmus Section, Operative, pp. A11-A18. Auckland City Council, Auckland, New Zealand.

Auckland City Council. 1999b. *Sheet D15 and Sheet E15 Planning Map 1, Isthmus Section, Auckland City Council Operative District Plan 1999.* Online at: http://www.aucklandcity.govt.nz/council/documents/district/maps/d151.asp and http://www.aucklandcity.govt.nz/council/documents/district/maps/e151.asp (accessed 24 January 2006).

Auckland City Council. 2003. *Auckland City: Growth Management Strategy.* Auckland City Council, Auckland, New Zealand.

Auckland City Council. 2004a. *Section 32 Report: Plan Change 61, Isthmus District Plan Glen Innes - Residential 6a and 8 Rezoning.* Auckland City Council, Auckland, New Zealand.

Auckland City Council. 2004b. Sites requested by submitters seeking to extend plan modificiation 61. Online at: http://www.aucklandcity.govt.nz/council/documents/district/updates/t061/PM61sitesmap.pdf and Summary of submissions: Plan modification 61 - Plan change. http://www.aucklandcity.govt.nz/council/documents/district/updates/t061/pm61summaryofsubs.pdf (accessed 10 June, 2006).

Auckland City Council. 2004c. *Glen Innes into the future.* Auckland City Council, Auckland, New Zealand.

Blakers, A. 2006. *Solarization.* The Australian National University, Faculty of Engineering and Information Technology, Department of Engineering, Centre for Sustainable Energy Systems. Online at: http://solar.anu.edu.au/docs/Solarization.pdf (accessed 4 July 2006).

Breuer, D.R. 1994. *Design for the Sun,* Working Manual. Vol. 1, Energy Efficiency Conservation Authority (EECA), Auckland, New Zealand.

Brown, L.R. 2001. *Eco-Economy: Building an Economy for the Earth.* Earth Policy Institute, Washington DC.

CAE (Centre for Advanced Engineering). 1996. *Energy Efficiency: A Guide to Current and Emerging Technologies: Buildings and Transportation,* Vol. 1. CAE, The University of Canterbury, Christchurch, New Zealand.

CAE and EECA (Centre for Advanced Engineering, and Energy Efficiency and Conservation Authority). 1996. *New and Emerging Renewable Energy Opportunities in New Zealand.* CAE and EECA, The University of Canterbury, Christchurch, New Zealand.

Camilleri, M.J. 2000. *Implications of Climate Change for the Construction Sector: Houses.* BRANZ Study Report No. 94, Wellington, New Zealand.

Camilleri, M.J. and Jaques, R.A. 2001. *Implications of Climate Change for the Construction Sector: Office Buildings.* BRANZ Study Report SR096, Wellington, New Zealand.

Carbon Trust. 2006. *What are Degree Days?* Online at: http://www.carbontrust.co.uk/ KnowledgeCentre/degree_days/ (accessed 28 July 2006).

Department of Trade and Industry (United Kingdom). 2006. *Our Energy Challenge: Power from the People.* DTI, London.

EECA (Energy Efficiency & Conservation Authority). 2000a. *Improving Energy Choices,* Fact Sheet 3, Solar water Heating, EECA, Wellington, New Zealand.

EECA. 2000b. *Passive Solar Design for New Zealand Homes.* Energy-wise Renewables – 11, EECA, Wellington, New Zealand.

EECA. 2000c. *The Dynamics of Energy Efficiency Trends in New Zealand: A Compendium of Energy End-Use Analysis and Statistics.* EECA, Monitoring and Analysis Unit, Technical and Research Group, Wellington, New Zealand.

EECA. 2001. *Solar energy use and potential in New Zealand.* EECA, Wellington, New Zealand.

EECA and SIA (Energy Efficency & Conservation Authority and Solar Industries Association). 2002. *Review of overseas initiatives that have been taken to increase the uptake of solar water heating.* East Harbour Management Services Ltd and Energy Library & Information Services Ltd, Wellington, New Zealand.

European Commission Directorate-General for Energy and Transport. 2006. *Managenergy* Online at: http://www.managenergy.net/indexes/I38.htm (accessed 4 July 2006).

European Green Building Forum. 2001. *Hockerton Housing Project, Southwell, UK, 1996,* Catalogue of Best Practice Examples, W/E Consultants Sustainable Building, The Netherlands.

Gabe, J. 2006. *Statistical Spotlight on Rising Demand for Electricity.* Unpublished document. Landcare Research, Auckland, NZ.

Ghosh, S. 2004. *Simple Sustainability Indicators for Residential Areas of Auckland, New Zealand.* PhD thesis, School of Architecture, The University of Auckland.

Ghosh, S. and Vale, R.J.D. 2006. *Settlement Form and Environmental Performance.* World Conference on Accelerating Excellence in the Built Environment (WCAEBE), Birmingham, UK, 2–4 October.

Ghosh. S., Vale. R.J.D. and Vale, B.A. 2006. Domestic Energy Sustainability of Different Urban Residential Patterns: A New Zealand Approach, *International Journal of Sustainable Development,* UK, 9(1): 16-37.

Hockerton Housing Project. 2006. Online at: http://www.hockertonhousingproject.org.uk/ (accessed 24 October 2006).

IDMP (International Daylight Measurement Programme). 2006. Online at: http://idmp.entpe.fr/stations/NZL03/NZL03.htm (accessed 29 July 2006).

Isaacs, N., Amitrano, L., Camilleri, M., French, L., Pollard, A. and Stoecklein, A. 2003. *Energy Use in New Zealand Households – HEEP Year7 Report- Executive Summary.* BRANZ Study Report: SR 122, Wellington, New Zealand.

Jiménez, V. 2004. *World Sales of Solar Cells Jump 32 Percent.* Online at: http://www.earth-policy.org/Indicators/2004/indicator12.htm (accessed 16 October 2006).

MfE (Ministry for the Environment). 2005a. *Review of Climate Change Policies – Energy (non-transport) and New Zealand Domestic Context.* MfE, Wellington, New Zealand. Online at: http://www.climatechange.govt.nz/resources/reports/policy-review-05/index.html (accessed 5 June 2006).

MfE. 2005b. *New Zealand's Greenhouse Gas Inventory 1990-2003.* MfE, Wellington, New Zealand.

MfE. 2005c. *Review of New Zealand's net position.* MfE, Wellington, New Zealand. Online at: http//www.climatechange.govt.nz/resources/reports/review-net-position-oct05/index.html (accessed 5 June 2006).

MED (Ministry of Economic Development). 2005. *New Zealand Energy Data File,* July. MED, Wellington, New Zealand. Online at: http://www.med.govt.nz/upload/28709/200507-a.pdf (accessed 5 July 2006).

MED. 2006a. *New Zealand Energy in Brief.* MED, Wellington, New Zealand. Online at: http://www.med.govt.nz/upload/32800/2006.pdf (accessed 5 July 2006).

MED. 2006b. *Data Tables for Electricity.* MED, Wellington, New Zealand. Online at: http://www.med.govt.nz/templates/StandardSummary_ 21414.aspx (accessed 2 October 2006).

Nottingham Weather Centre, United Kingdom. 2006. Online at: http://www.worldclimate.com/cgi-bin/data.pl?ref=N53W001+1102+03354W (accessed 28 July 2006).

NIWA Science. 2006. *Climate–Energy Matters: Greenhouse gases from residential energy use.* National Centre for Climate and Energy Solutions. Online at: http://www.niwascience.co.nz/ncces/cem/2002-03/residential (accessed 5 July 2006).

PCE (Parliamentary Commissioner for the Environment). 2005. *Future Currents: electricity scenarios for New Zealand 2005-2050.* PCE, Wellington, New Zealand.

Redshaw, D.J. and Dawber, K.R. 1996. *Sustainable Energy Options for New Zealand.* The University of Otago Press, Dunedin, New Zealand.

Rylatt, M., Gadsen, S. and Lomas, K. 2001. GIS-based decision support for solar energy planning in urban environments. *Computers, Environments and Urban Systems,* 25:579-603.

Solar Industries Association. 2006. Online at: http://www.solarindustries.org.nz/info_solar.html (accessed 4 July 2006).

Statistics, New Zealand. 2001. *New Zealand Census of Population and Dwelling 2001- Mesh block Data.* Statistics, NZ, New Zealand.

Steven, S., Lloyd-Jones, D. and Prasad, D. 2005. Building design and environmental concepts.. In: Prasad D. and Snow, M. (eds) *Designing with Solar Power - A Source Book for Building Integrated Photovoltaics (BiPV),* chapter 1. SOLARCH Group, Centre of Sustainable Built Environment, University of New South Wales, Image Publishing Group and Earthscan, Australia.

US Department of Energy. 2005. *Become One in Million - Partnership Updates - Million Solar Roofs and Interstate Renewable Energy Council,* Annual Meeting, Energy Efficiency and Renewable Energy, National Renewable Energy Laboratory, US Department of Energy, Washington, DC.

Vale, B., and Vale, R. 2006. *Zero energy housing retrofit.* Paper presented at PLEA 25th International Conference on Passive and Low Energy Architecture, Geneva, 6 – 8 September.

World Climate. 2006. Online at: http://www.worldclimate.com/ (accessed 29 July 2006).