THE DENSITY TRADE-OFF

Does High Rise Living Contribute More than Living in Detached Dwellings to Greenhouse Gas Emissions?

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INTRODUCTION

Abstract

Density increases are generally accepted as reducing the carbon involved in urban transport. This relationship has been shown consistently between cities (through the Global Cities database) and within cities like Sydney and Melbourne. However the density increases in buildings are more controversial with several studies suggesting that high rise buildings are much more greenhouse intensive due to their shared spaces such as lift lobbies and underground car parks and their extra embodied energy in the structure. There is thus confusion amongst policy makers who see a trade-off between increasing density for transport Greenhouse Gas emissions (GHGe) savings but reducing density for building GHGe. This confusion is further exacerbated by the lack of data supporting this viewpoint or indeed, any specific threshold beyond which an increase in density would mean an increase in GHGe.

The resolution of this trade-off is examined by showing a) that the increase in GHGe associated with high rise living is not as significant as some of the recent Australian literature suggests; b) the transport gains in GHGe are far greater due to density than any losses in GHGe due to the high rise buildings; and c) when appropriate low carbon design is applied, the attributes of density and high rise significantly reduce greenhouse gas emissions compared with low density, detached dwelling, especially when the dramatic reductions due to co-generation are factored in.

Background

There is now a general consensus that climate change is anthropomorphic and in order to prevent runaway climate change we need to manage global temperature increases to not more than two degrees greater than pre-industrial levels.

Looking at cities as a source of GHGe there is some discrepancy over how much the built environment is responsible for (Clinton Climate Initiative, 2010; Dhakal, 2010; Satterthwaite, 2010). With figures ranging from 30% up to as much as 70% it is clear that, regardless of the variations in the literature, the figures warrant the need to address the urban environment as a significant cause of climate changing emissions. The contribution of transport to the figure is significant and it is a question of where the boundaries are set that influences the large variation in the numbers above. Energy use in buildings and transport are certainly two of the biggest contributors of GHGe in the built environment.

The United Nations Framework Convention on Climate Change recognises the significance of urban development and paves the way for a shared vision towards “a low-emission development strategy that is indispensable to sustainable development” (UNFCCC, 2009). There is clearly going to be a need for cities to play their part and with over half of the world’s population now living in towns and cities, and a trend that indicates a continuing move from regional to urban living, there is clearly good reason to focus on how we go about planning our cities for the future. The relationship between density and GHGe is fundamental to the planning of cities.

Literature Review on Density and GHGe

The idea that high density buildings may have higher energy use associated with them comes as a surprise considering literature over many decades which showed that buildings with shared walls and floors could substantially reduce energy in heating and cooling (the shared insulating effect). Traditional buildings clustered together to achieve this effect and studies like the seminal Costs of Sprawl Report in 1974 by the Real Estate Research Corporation, were confirmed again in an update in 1998 and by numerous studies through the Urban Land Institute and Smart Growth America (eg. Ewing et al., 2007). However recent studies in Australia have given a sudden burst of interest that this may not be the case.

The Australian Sustainable Built Environment Council (ASBEC) are one body who will undoubtedly have the ear of the State planners. They are currently embarking on a project which aims to explore the links between GHGE from urban transport and land use within our cities and to inform public policy and government decision making (ASBEC, 2010). This work is still at an early stage but it does suggest a challenge to the concept of urban consolidation being the most effective way of tackling GHGe. The report cites two sources; the Australian Conservation Foundation's online Consumption Atlas (the Atlas) (ACF 2009), and Perkins article on "Transport, Housing and Urban Form" (2009).

The ACF research uses an economic Input-Output Life Cycle Assessment approach in dealing with GHGe, and has extended the boundary conditions to include consumption beyond the household. The inclusion of Australian industries encompasses the GHGe produced through the production and distribution of goods, arguably, provides a more realistic picture of the GHGe individuals are responsible for. It further suggests that, "for households to make a serious dent in greenhouse emissions, they must go well beyond merely reducing energy and petrol use" (Australian Conservation Foundation, 2007). By including GHGe associated with the production of food, clothing, furniture and appliances, tobacco and alcohol to name but a few, the percentage of GHGe associated with Household Use and Transport drops to about 30%. Acknowledging that urban living offers more opportunities than sprawling suburbs for reducing environmental impacts through reduced car use and lower energy costs per person, it is noted that the data presented shows inner city suburbs having significantly higher GHGe than suburban areas. The conclusion drawn is that higher income levels are linked with higher consumption levels and this occurs in inner city areas which are associated with higher incomes. The dataset that the research depends on is the ABS household expenditure data. The work is completely aspatial and does not seek to determine energy use by actual data but by implied data from household income. This is highly controversial as a means of determining energy use and goes against all the studies which show actual energy use is highly spatially determined both because of transport availability and land use patterns. The work should not be used for spatial planning purposes as ASBEC seeks to do.

Troy et al. identifies the importance of developing measures of energy consumption "that might be used in reviewing policy directed toward reducing energy consumption (and) as an essential step in developing a new planning tool" (2003). In determining the boundaries of measured energy, some considerable detail is explored in the six Adelaide case study areas (CSA's) used in the study. Operational energy (consumed by buildings and transport), embodied energy associated with the building stock, roads, the road transport fleet, and other infrastructure. The study draws on data from a number of data sources including the ABS associated with census collector districts (CSD's), as opposed to collecting the raw data directly – an important step in providing a method that can theoretically be applied to any CSD across the country and therefore allow for comparisons to be drawn across the country.

There were a number of weaknesses in the method that were highlighted by the author, the most contentious being that of operational transport emissions. The South Australian annual average figure for vehicle travel was used, combined with census data for travel to work estimates – all in all the data could only be regarded as providing an order of magnitude at best. It is in fact neglecting all the data on Vehicle Kilometres Travelled (VKT) collected for decades. It could be argued that this work should not be used for comparing spatial planning policy as it does not use spatial data that is available.

The Perkins study (2009) is also a problem as it does not compare like with like. The sample of city centre apartments consists of 41 households from only three apartment buildings, 64 predominately 2-storey town houses in an old inner area and 164 detached homes on the urban fringe. The study itself does not claim to have provided the data base for making the kinds of claims that are now being made.

A much bigger study of a sample of multi-unit residential buildings in Sydney for Energy Australia (EA) examines energy use and peak energy demand over a mix of high rise, mid rise, low rise, townhouses and villas (Myors, O'Leary, & Helstroom, 2005). The energy auditing that was completed covered the apartments but the particular focus was on the common areas of the buildings including, lifts, pools/gyms as well as central cooling and ventilation systems. Close to 4000 apartments were assessed in the study, possibly the largest sample examined in a study of multi-unit buildings in Sydney.

The results of the study reflect that people living in apartment buildings produce more GHGe than those in detached dwellings and, townhouses and villas appear to be the most efficient on a per capita greenhouse gas basis. This was explained by energy consumption in common areas and lower occupancy rates of apartments over detached houses. However the authors acknowledged that "with more thoughtful selection of common area technologies, many high rise buildings could enjoy large energy and greenhouse savings." In addition, 88% of the sample of high rise buildings in the study included one or more swimming pools – so it could be argued and indeed is acknowledged by the authors that there is a possible bias towards more prominent luxury housing estates in the selection. Furthermore, the study did not include actual occupancy rates of the apartments, nor the number of bedrooms – which would be influential in the number of occupants in a particular apartment. Instead, the average figures across Sydney from the ABS were used, resulting in some fundamental flaws in this study.

HIGH RISE VS. DETACHED DATA

The definition of "high rise" in the context of this paper is anything over three stories. Historically, high rise construction of any sort was dependant purely on the means of negotiating the heights that it was possible to build with the "new" form of steel framed construction. The invention of the elevator saw the birth of tall buildings in New York and Chicago in the late nineteenth century. Today buildings three storeys and over must be served by an elevator which would suggest anything taller than a typical town house is high rise.

Operational Energy

The EA report defines high rise as nine or more storeys, mid rise from four to eight storeys and low rise being up to three storeys. Figure 1 shows the emissions per capita for each of the housing types, created using data from the report.

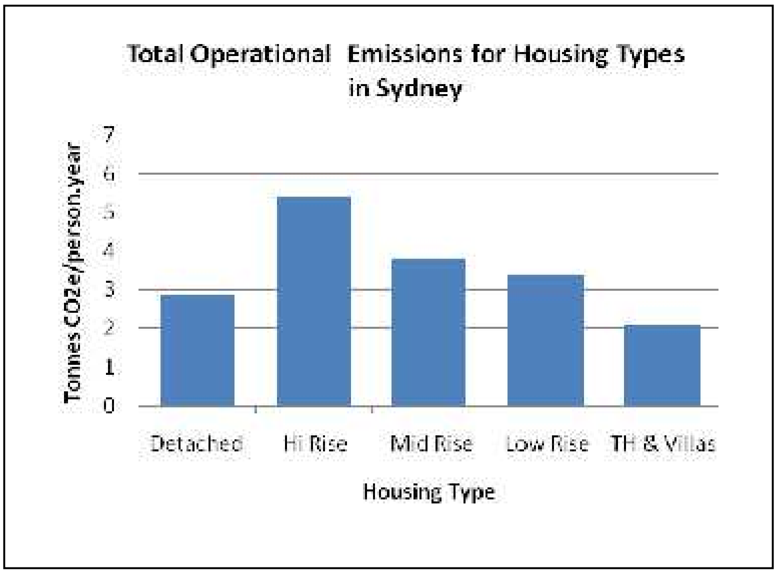

Figure 1: Energy Australia Figures for per Capita Greenhouse Gas Emissions

Considering the possible bias towards luxury hi-rise that the authors of the original study referred to, Rickwood broke down the hi rise component of the sample into Luxury Hi Rise and Hi Rise, where Luxury Hi Rise only included those developments with a pool or a spa on the basis that these items are regarded as luxuries and contribute significantly to the energy use of the buildings (Rickwood, 2009).Figure 2 demonstrates the breakdown in accordance with Rickwood's observations.

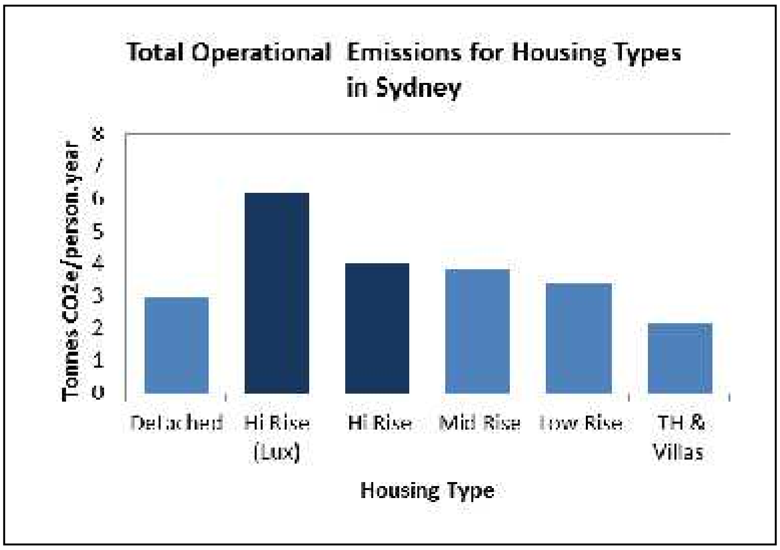

Figure 2: EA Study figures including a split in Hi Rise Showing a Component of Luxury Hi Rise

It still shows a trending increase in GHGe emissions in multi-unit development, but it is now much less dramatic. Unfortunately this explanation is undermined by the fact that, from this data set, the sample is not representative because 15 of the 17 developments classed as high rise have a pool or a spa. Although this questions the validity of the explanation, it reinforces the idea that the dataset is weighted towards a greater number of more affluent suburbs.

It is also acknowledged that the emissions associated with pools and spas can vary dramatically thus the choice of the inclusion of pools as a significant contributor to energy consumption may not be truly reflective. Indeed, the Energy Australia study has a comparative study of two high rise apartment blocks both of which have pools and spas. The first of the two examples has a 75,000 litre pool, spa and sauna that, when combined, are responsible for 6.1% of the building's total greenhouse emissions. The second example has a 48,000 litre pool and the combined pool and spa emissions account for 22% of the building's total emissions. Interestingly, the latter example performs better in terms of total annual per capita greenhouse gas emissions for the building by a significant margin.

Other factors that may also be considered as reflective of 'luxury' is floor area or number of bedrooms. Data on these parameters is not included in the data set therefore it cannot be analysed in this paper but it is a serious flaw if this study is used as more than an indicative exercise.

A more effective energy related explanation for the difference in GHGe is based on the energy use for heating and cooling. To do a like for like comparison with detached housing, average figures for high rise with and without centrally situated heating and cooling systems were calculated and are shown in Table I. In this exercise high rise represents a combined average for all the multi-storey blocks; low, mid and high rise.

Table I: Average GHGe Emissions Showing Hi Rise with and without Central Heating and Cooling

	Tonnes CO2e/(person.yr)
Hi Rise (with Central Heating and Cooling)	**6.47**
Hi Rise (no central heating or cooling)	3.59
Low/Mid/TownHouse/Villa	3.23
Detached	2.83

The centrally heated and cooled figure for high rise shown in table I shown in isolation, demonstrates the significance of this design option which, when included with the rest of the data will have a huge impact on the amount of GHGe high rise is responsible for, as clearly demonstrated in figure 1. The figures show that by comparing "like for like" there is still an increase in emissions with height however the increase isn't large. The detached figure uses the average energy figure for detached dwellings across East Sydney and is thus a more genuine average, but the actual figure used for the hi-rise is now down to just a few eligible developments to be considered as average for a reasonable comparison. Otherwise the Detached sample would have to have included only centrally heated and cooled homes.

High rise that emits less GHGe can be designed (also demonstrated in table 1) using a number of options that improve on heating and cooling from centrally located plant with alternative and/or higher efficiency options - the 6.47 figure from table I is large, not because of the high rise nature of the developments but rather due to the heating and cooling system installed. This again means that spatial planning conclusions should not be based on these data.

Embodied Emissions

A recent report by Kinesis for the Department of Innovation, Industry, Science and research looks at embodied emissions for mult-unit and single dwellings (Taper et al., 2010). Not surprisingly, the use of denser materials in multi-unit construction showed high rise to be significantly greater in embodied emissions when compared with single dwellings. In addition, the study also compares embodied emissions in the infrastructure (roads and services) which shows that the infrastructure required to support the detached dwellings is more than six times greater than that for higher density forms. However, when considered as equivalent years of operational emissions, multi-unit performed poorly, being equivalent to approximately four years of operational emissions compared with two years for single dwellings. There are many opportunities to reduce embodied energy in high rise, for example, the use of fly ash (a recycled product) as a substitute to cement in concrete has significant impact in reducing GHGe due to the high embodied content of cement.

Clearly there are alternative materials that can be sourced that will reduce emissions and it will depend on the existing nature of building styles whether the impacts will favour one dwelling form over another or whether there will be simple across the board savings. For example in New South Wales and Victoria there is a lot of lightweight low carbon construction practices in single residential dwellings so any reductions in heavy duty, carbon intense techniques will close the gap in embodied emissions between detached and multi-unit dwellings. This would not necessarily be the case in Perth, where detached dwelling construction practices favour heavy duty materials, mostly double brick.

As embodied emissions are emitted once only (with the exception of ongoing maintenance works) and mostly occur when a development is built, they cannot be easily included with the data on annual operating emissions that are shown in this paper as per capita figures.

HIGH RISE VS. DETACHED COMPARISON INCLUDING TRANSPORT

Transport Methodology

Drawing on the work by Trubka et al. the model that was developed to predict GHGe associated with transport from density or Activity Intensity (population plus jobs in an urban area) was used (2008). To establish a quantitative model examining emissions associated with city planning, Trubka draws on data from a previous study completed at Murdoch University which estimated fuel use at Local Government Authority level (Chandra cited by Trubka, 2006). The study regressed several transport-influencing factors and the best three were chosen to run a multiple regression analysis. The three parameters are:

- Distance to CBD - Linear distance to the CBD in kilometres
- Activity Intensity - calculated by adding together the population (in number of persons) and the number of jobs per hectare for a given area
- Transit Access - Percentage of area with public transport services beyond a specified threshold

Theoretically, activity intensity doesn't rely on distance from the CBD, rather the concept that there is a critical mass in terms of activity, below which transport emissions increase exponentially. Interestingly, the multiple regression analysis demonstrated such a strong correlation between distance from CBD and activity intensity that they could be considered as surrogate parameters for one another.

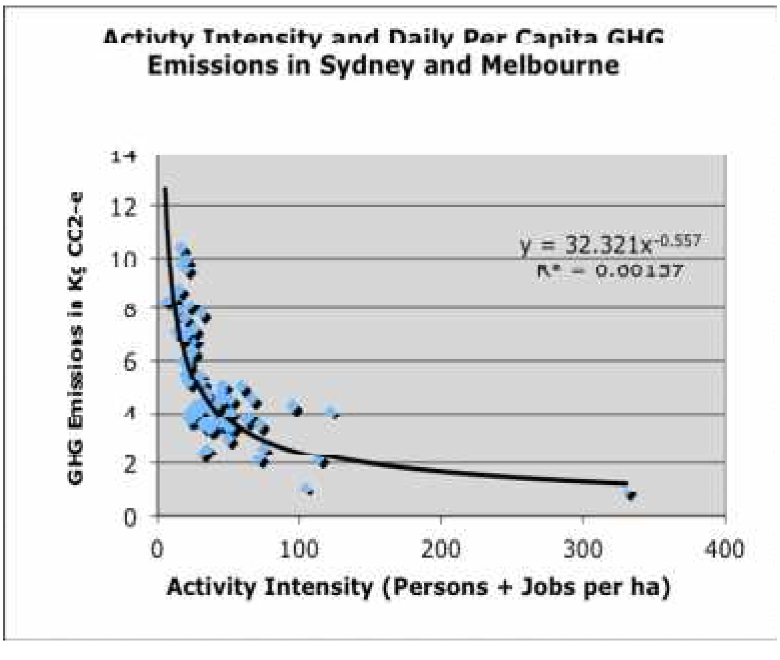

Figure 3: Transport Emissions Regressed on Activity Intensity.

The transport emissions analysed in the study are those from private motor vehicles based on actual household travel behaviour. The study goes on to explain that demand-based solutions reduce the need for private travel and, in some cases, remove the need for motorised travel altogether by bringing people closer to their desired destinations and making non-motorised modes of travel more attractive. It is acknowledged that emissions associated with transit alternatives are excluded from this study though the same basic patterns were found by Newman and Kenworthy (1989, 1999, 2006) in older studies in Australian cities and indeed in many other cities around the world, and this was for total transport fuel vs. density.

The model presented in Figure 3 suggests that 60.16% of daily per capita transport emissions can be explained by an area's Activity Intensity across LGA's in Sydney and Melbourne.

The research by Newman and Kenworthy (2006) shows that there is a threshold of activity intensity around 35 per hectare where automobile dependence, and therefore private transport emissions reduces significantly. Activity intensity across Sydney varies dramatically. At its highest it is 330.6 in the CBD, dropping to 5.3 in the Blue Mountains. Activity intensity includes all urbanized land including roads, parks and open spaces to give a true reflection of the area in question.

Based on the data in Trubka et al (2010) a figure of 15 per ha has been selected for detached houses that can be considered a reasonable reflection of a low density suburb dominated by residents rather than jobs. For the medium density townhouses and villas a figure of 50 per ha is used and the high rise uses 100 per ha. These estimates of density can be used to estimate typical transport patterns associated with the different housing types.

It is recognised that the Activity Intensity figures analysed in Chandra's data are based on LGA areas and therefore will lend itself to a cleaner, less interesting, set of results as depicted in figure 3. Aggregated data such as this will not identify potential anomalies. For example a high intensity development situated in a typically low intensity suburb will undoubtedly adopt a travel pattern (and associated GHGe) that reflects the available transport options of that particular low intensity suburb (and vice versa). However, the data needed to do a more granular study is difficult to obtain particularly the data relating to the transport side as the sample size is too small. A detailed analysis such as this is beyond the scope of this paper.

Adding Transport Emissions to the Data

Figure 4 shows the impact of adding a predicted figure for private transport related emissions based on Trubka's model, to the emissions presented in Table 1 - the total GHGe across the building types. This shows that detached dwellings emissions increase to a point where they are now higher than both the multi-unit development figures.

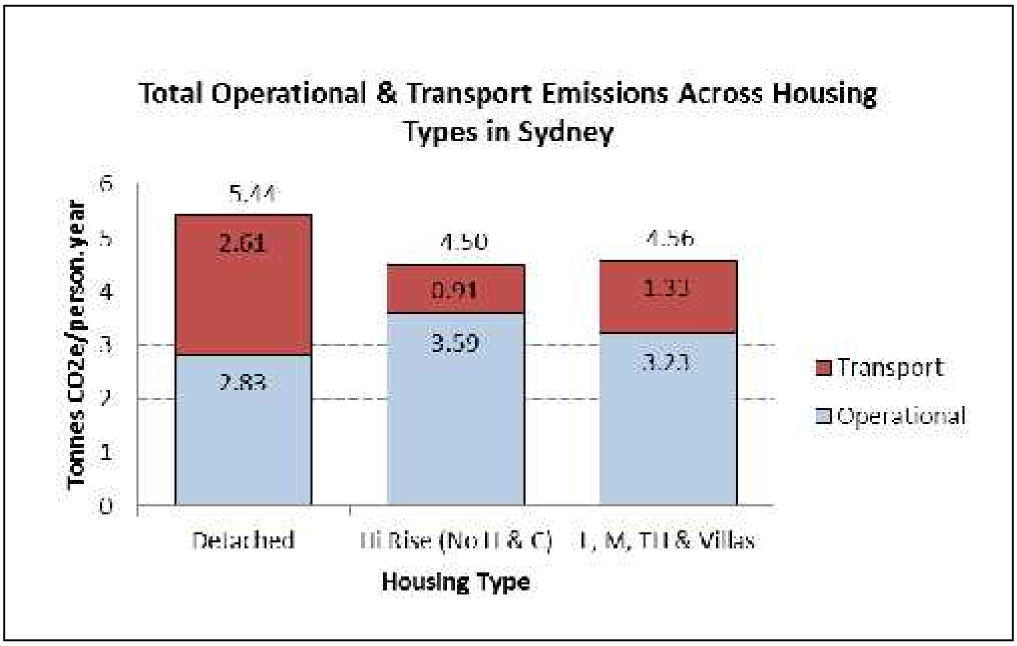

Figure 4: Total Operational & Transport Emissions across Housing Types in Sydney

Multi-unit developments are still ahead when looking at operational emissions alone (a fact that is highly suspect given the analysis above) but when transport emissions are included detached dwellings suffer most, clearly leading the multi-unit types by a significant margin. The multi-unit dwellings combined GHGe appear consistent across the various forms of multi-unit design options when looked at this way.

LOW CARBON HI RISE

Importantly, consideration must be given not only to existing construction methods, but how we can build more efficiently with respect to greenhouse gas production for all building types and scales that are typical in the built environment, into the future. The Warren Centre is now undergoing a detailed study of the potential for Low Carbon Hi Rise development. There appears to be considerable potential for this to be achieved as set out below.

A report by Kinesis which looks at evidence based decision making for emissions reductions in cities includes an analysis of a variety of interventions and technologies designed to reduce GHGe (Taper et al., 2010). The analysis looks at four case studies, two urban infill and two urban fringe. Table 5 lists the approaches modelled by Taper and the potential reduction of GHGe emissions.

The model does not discuss the emissions reduction potential in terms of single or multi-unit dwellings but rather *urban fringe* and *urban infill* case studies with various housing types implied. The urban infill cases encompass 4,350 dwellings with just under 4,000 being multi-unit dwellings and the balance being townhouses or villas. The fringe cases total nearly 13,000 dwellings, nearly 4,000 detached, 5,500 attached and the balance in multi-unit dwellings. With 91% of the urban infill numbers being multi-unit dwellings it is not unreasonable to consider this as a case consisting of multi-unit dwellings with a small margin. In terms of the comparability of the fringe cases with detached, the correlation is less convincing. With about a quarter of the dwellings being multi-unit, you could argue that the modelling for cogeneration and solar hot water is questionable to a degree. If the multi-unit element was to be removed from the single dwelling sample the cogeneration savings would be lost to some degree. Likewise with MEPs and solar water, probably to a lesser degree. However solar PV would improve single dwellings – possibly as much as 2%. For the purposes of this study we have assumed that the benefits and losses that the single dwelling figures would be subject to have balanced themselves out, therefore the figures from the original modelling have been left as is.

Table 2: Percentage Reductions in GHGe from Modelled Interventions

	Single Dwellings	Multi Unit Dwellings
The Renewable Energy Target	6.5%	6.5%
Cogeneration and Trigeneration	8.0%	27.0%
Interior lighting	3.0%	3.0%
Minimum Energy Performance Standards	5.0%	3.0%
Solar Hot Water	6.0%	11.0%
Solar PV	6.0%	1.0%

The Renewable Energy Target has been operating in two parts since January 2011 – the Small scale Renewable Energy Scheme (SRES) and the Large scale Renewable Energy Target (LRET). Combined, the new LRET and SRES are expected to deliver more renewable energy than the previous 45,000 gigawatt-hour target in 2020. The RET policy is basically a fuel switching measure and should reduce operational emissions in any new development by between six and seven percent regardless of the building form.

Cogeneration or Combined Heat and Power (CHP) is a term for a system that produces low or zero carbon electricity and uses the waste heat from the process for other functions such as heating hot water and space heating. Tri-generation adds another process to the system. By passing some of the waste heat through a heat-driven absorption chiller, chilled water is produced which can be used for air cooling.

Installing this kind of generating system locally, reduces losses normally incurred through transmitting high voltage electricity over long distances but more significantly, the benefits of switching to a low carbon fuel in natural gas immediately reduces emissions by approximately 50% compared with coal-fired electricity generation. Combined with the waste heat recovery component (towards hot water, heating and cooling) the efficiency of the system can lead to an overall reduction in GHGe of around 70% if properly designed. Cogeneration requires density or compact design in order to be most effective. Efficiency gains through the heat recovery process only add value when the heat is used and thermal energy, by its nature, is restricted in where it can be used because of heat losses over distance through the infrastructure. The modelling by Taper reflects the disadvantage that single dwellings have by returning a modest 8% reduction in emissions compared with 27% for multi-unit dwellings.

With the phasing out of incandescent lighting and the growing acceptance of high intensity LEDs there is clearly some scope to reduce GHGe with the latest available lighting technologies. The modelling assumes that the average efficacy of residential lighting can be doubled for single and attached dwellings and improved by 70% for multi-unit developments although it is unclear why there would be a difference. An improvement of 3% for all dwellings was modelled and that figure is demonstrated in this paper. One of the outcomes of the EA study was for the consultants involved in the energy analysis to identify specific initiatives that would save energy for the two sites involved in the comparative analysis. Lighting controls for common areas (e.g. Car parks, hallways, fire stairs, lobby and external lighting) was identified but no indication was given as to how much energy could be saved.

Minimum Energy Performance Standards targets (MEPS) have been in place in Australia since 1999, setting mandatory targets for industrial, commercial and residential equipment in terms of electricity consumption (Australian Government, 2010). The standards have proved effective across all areas and new standards are being introduced regularly to encompass an increasing number of appliances across the board. Refrigerators and air conditioners have seen significant improvements of 40% and 20% respectively in recent years. The fringe/detached case. This could be due to the assertion that detached homes tend to be larger with more habitable rooms than units therefore there is likely to be more appliances in the household, more volume that may require heating or cooling and less shared insulating effect – the effect of waste heat from one house helping to heat its neighbour..

Solar hot water includes the ‘boost’ element needed from gas or electricity to achieve the thermal loads required for hot water demand. The modelling also includes the penetration rates for existing electric and gas boosted systems. The final figures represent a situation where all single and attached dwellings are fitted with solar hot water. Assuming then that the existing penetration rates reflect business-as-usual rates of take-up, the percentage improvement in the model is a reasonable figure to use.

Solar Photo-voltaic (PV) is based on similar assumptions as those for solar hot water in terms of existing technology penetration. The PV capacity modelled is a 1kW grid connected system.

Both of the above technologies require available roof space so the modelling assumes deployment over single and attached dwellings although it could be argued that even with the limited space afforded multi-unit blocks in terms of roof area per dwelling, there is still the potential to use renewable electricity in common areas and hot water where a central hot water supply system is specified.

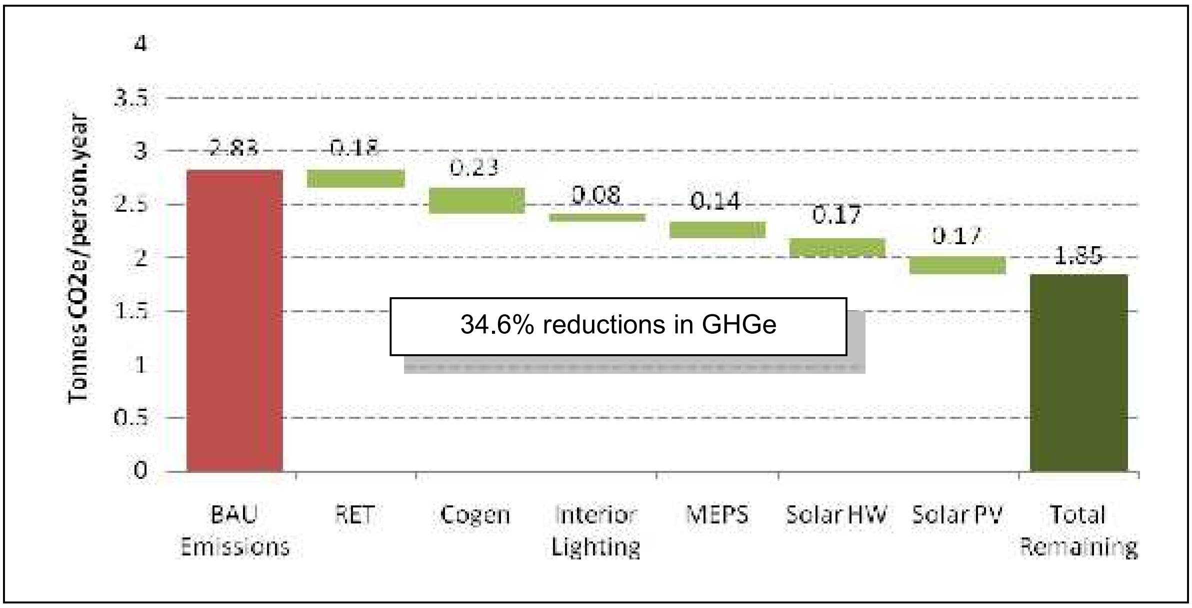

Figure 5: Modelled GHGe Emissions Reductions Options for Detached Dwellings

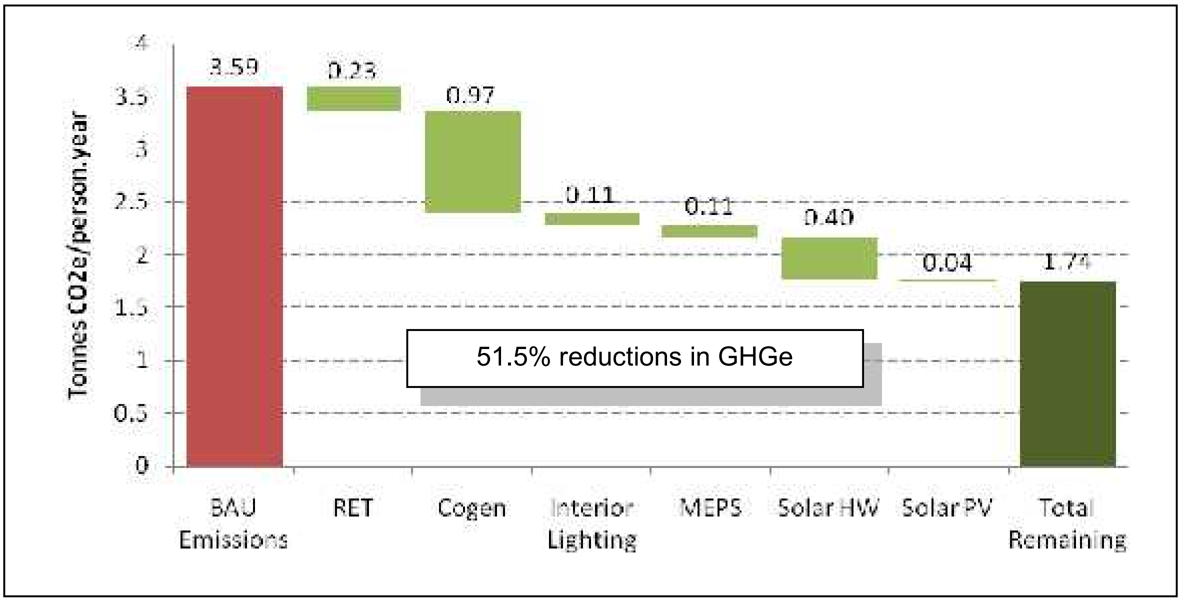

Figure 6: Modelled GHGe Emissions Reductions Options for Multi-Unit Dwellings

Figures 5 and 6 shows, in theory, how these interventions could greatly reduce the operational emissions of the dwellings from the Energy Australia study.

The use of Cogeneration is the single intervention that has the biggest impact for both detached and multi-unit dwellings in terms of reducing GHGe emissions. The most significant observation to be made is the difference that the multi-unit dwelling form makes over that of detached dwellings, with reductions of 27% and 8.1% respectively.

Construction into the Future

The Interventions discussed above, with the exception of the bolt-on solar technologies, are all supply side approaches to reducing emissions. What has not been explored in any detail is the impact of improvements in the thermal efficiency of the buildings themselves – arguably the most significant demand side strategy in reducing GHG emissions.

The Australian Building Codes provide the mandatory minimum standards that all buildings need to adhere to in this regard and it's interesting to note how far behind Australia is in terms of the thermal performance of the building fabric (Horne et al., 2005). Europe is far ahead of Australia in this regard, particularly with programmes like the *passivhaus* standard developed in Germany.

EXCLUSIONS

This paper does not include emissions associated with public transport or embodied emissions in private transport vehicles. Neither does it go into the question of any other goods (including food), services and resources. This ties into the question of boundaries and where the responsibility lies in accounting for specific carbon. For example, are the embodied emissions of a car made in Japan accountable to the place the car was made or to the end user driving the vehicle around Sydney's suburbs? A pragmatic viewpoint could suggest that in the context of urban design and transport, we only deal with emissions that may be considered as being caused by the development project itself. Hence the emissions from fuel do need to be considered.

CONCLUSION

The figures reproduced in this paper are generated from relatively simple modelling. The objective is to demonstrate that, should reducing GHGe be one of the primary objectives when designing and constructing buildings in the future, it is easy to see there are ways of making reductions across all building forms. The concern lies with the current inference that building taller equates to greater carbon emissions. For example, the study that forms the heart of this paper has a sample of 45 developments totalling over 4,000 dwellings, and clearly demonstrates that, looking at operational emissions alone, there is a correlation between height and greenhouse gas emissions. When re-examined to take out the obvious factor of wealthier developments with substantial energy consuming pools and spas (and bigger dwellings), there is almost no difference in the high rise compared to other building forms and is likely to be less when more global literature is considered. Better studies could confirm this but no spatial planning conclusions should be taken from these very simple Australian studies.

When the multi-unit development is compared with detached dwellings, and the transport emissions are then applied, the most noticeable result is the exaggerated position of the detached dwellings in comparison to all other building types. There is little doubt about this important aspect of spatial planning.

These data suggest that there is indeed no density trade-off when it comes to greenhouse emissions. This is especially true when it is considered how easily reductions can be made in GHGe when new design and technologies are introduced. The role of co-generation is especially important in enabling substantial reductions in operational energy and this works best in compact, high density areas.

There is obviously a cultural reaction to high rise that can be eased by ensuring high rise is placed in specific areas such as quality transit routes, and also requiring high quality design. However the data to suggest that high rise should be avoided for GHGe savings is inconclusive, and with architects and designers seeking to reduce GHGe wherever possible in their designs, this view appears to be unsubstantiated..

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