511: High Density, Low Energy: Achieving useful solar access for Dublin's multi-storey apartment developments

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Abstract

Solar energy has quantitative and qualitative benefits in the city, from reducing energy consumption to improving both indoor and outdoor amenity. However, gaining access to solar energy becomes increasingly difficult in high density developments, where orientation may not be optimal and obstruction is almost inevitable. Achieving a sensible balance between density and solar access is therefore a critical factor in sustainable urban design, however this balance will vary according to the climate, the site, and the brief of individual developments.

This paper documents how a multi-storey apartment block in Dublin can be designed with respect to these factors in order to reduce energy consumption through solar access without compromising built density. The design research is divided into two distinct research phases. The first phase is concerned with the site massing, and uses solar envelopes to determine the highest buildable volume relative to solar geometry and occupancy patterns. The second phase of design focuses on individual apartment units within this optimised site massing, and assesses the useful benefits of solar access in terms of daylighting, passive solar heating, and potential for integration active solar systems. The final design is assessed in terms of the resulting density achieved, relative to the actual useful contribution of the sun to the developments total energy consumption.

Key words: Passive Solar and Daylight Design

1.0 Introduction

Dublin is a low density city with housing densities around 15 - 20 units / hectare [1] and a population of 1.18 million [2]. This population is set to dramatically increase in the coming years, and in an effort to prevent the urban sprawl this additional population is likely to produce, significant emphasis has been placed on reversing the trend of low density development. The Dublin City Development Plan 2005 – 2011 [3] provides a planning framework for all developments in the city and defines maximum plot ratios[1] and site coverages[2] for all new developments. Although these densities are low compared with other European capitals, the planning policy of urban densification is nevertheless beginning to redefine Dublin as a more sustainable city.

One major impact of this policy of urban densification is the reduction in solar access. Urban environments do not generally provide favourable conditions for solar access and as buildings become taller or deeper with higher density development, the potential for profiting from solar energy becomes increasingly difficult. Ralph Knowles, author of many papers on solar access, summarises the dilemma as follows: *'If you do not have access to the sun then you cannot use it' [4].*

The word 'use' must be defined for the Irish context. The Dublin City Development Plan refers only to solar access for daylighting and amenity, however the sun can potentially play an important role in reducing urban energy consumption through passive solar design and active energy systems. Yannas [5] lists the principal ways in which solar energy can reduce the energy demand of a city as follows;

- Reduction of space heating demand;
- Quantitative contribution to day-lighting inside and outside;
- Heat supply for solar heated hot water;
- Electricity generation with Photo-voltaic panels

Although the Development Plan regulates solar access in general terms, there is no quantitative assessment of these additional benefits. This is understandable given the difficulties such an assessment would present. Firstly, in order to guarantee solar access to a single individual building, the morphology of all the surrounding buildings would have to be optimised. Secondly, as will be shown in this paper, the actual useful benefit of solar access cannot be generalised, but instead must be considered for each individual case.

1 A plot ratio is calculated by dividing the net floor area of all buildings on the site by the net site area
2 Site coverage is the percentage of total site area occupied by structures

2.0 Design objective

How then, can a sensible balance be achieved between high density development and solar access which will usefully influence the energy performance of the development? This paper investigates this question through a process of design research. The vehicle for the research is the design of a high density residential development in the Cork Street area of Dublin, which has seen rapid urban densification in the last five years. The design research specifically addresses two key questions at both macro and micro scales:

- What urban morphology guarantees solar access, without compromising the density of development?
- How useful can the sun be in terms of lowering energy consumption once a building has access to it?

The site selected is a large brownfield site (6.6ha), and is surrounded mostly by low density residential and light industrial developments, with the exception of a 6 storey apartment block to the south, and a sports centre to the north (fig. 1). The large scale of site is key in terms of optimizing both urban morphology and individual building for solar access.

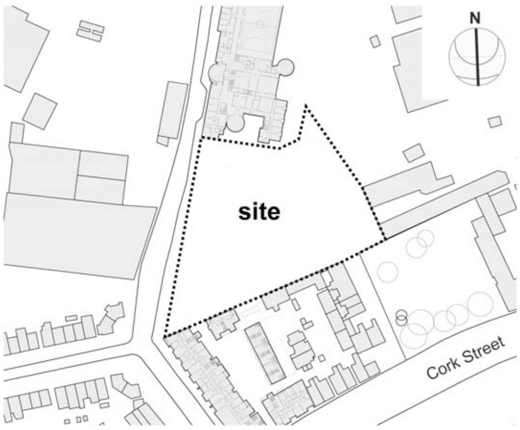

Fig. 1: Site in Cork Street part of Dublin

3.0 Defining an urban morphology optimised for solar access

3.1 Legislative context

Both density and solar access are regulated through the Dublin City Council Development Plan. Plot ratios of 3.0 are suggested for inner city sites such as Cork Street (although recent residential developments such as Charlotte Quay in the Grand Canal Basin have exceeded this figure with a plot ratio of 3.8). Legislation of solar access is vaguer, with limitations on the number of north facing single aspect units, and control of building heights. For quantitative guidance, the Development plan points to BRE Guidance for assessing Daylight / Sunlight which provides recommended daylight factors, vertical sky components, and hours of overshadowing. There is no guidance however, on how density and solar access should interrelate. What would the maximum buildable density be if developed according to solar access criteria?

3.2 Applicability of the solar envelope

Using solar geometry as a parameter to inform urban density is not a new field of research. 'The Solar Envelope' developed by Ralph Knowles has been used as a planning tool in Los Angeles but is unknown in Dublin. The solar envelope is defined as the maximum enclosing volume achievable within a set of temporal and spatial parameters, which ensures that adjacent buildings are not overshadowed. Fig. 2 shows a solar envelope on a 15 x 36m city grid and identifies the parameters which generate it; (a) solar geometry (b) the physical boundaries of the surrounding properties beyond which shadow should not fall (shadow fences) and (c) the chosen period of access to sunshine for those boundaries (cut-off times).

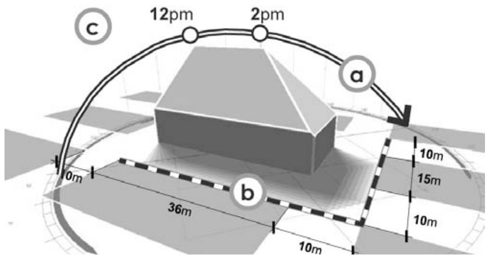

Fig. 2. Parameters used to generate a solar envelope

The reason perhaps that the solar envelope has not found favour among Irish Planners might be the preconception that there is not enough sun, and what there is, is too low. Certainly, at the latitude of Dublin (53º4'N) solar altitudes are shallow, ranging from 13° in winter, to 60° in summer, and this results in significant overshadowing and obstruction. However, an analysis of historic climatic data reveals that Dublin enjoys 23% clear skies (0 - 2.4 Oktas) per annum, and only 18% of fully overcast skies (8 Oktas), according to the CIE definition of clear and overcast. An investigation into urban form derived from solar geometry is therefore statistically justified given that the sun is only fully overcast for less than 20% of the time.

3.3 Parametric analysis

A series of parametric tests were undertaken to evaluate the solar envelope as a tool for urban planning at the latitude of Dublin. Using a 15 x 36m city grid, a series of envelopes were generated for three orientations, allowing solar access to adjacent blocks within different daily / hourly cut-off times. Figure 3 shows the range of volumes generated and the solar envelopes for the May 21st to July 21st series. As would be expected, the results demonstrate that a solar envelope with the least temporal constraints achieves the highest volume. Thus, if only two hours of insolation per day is required between the months of May 21st and July 21st, a buildable volume of 19,049m³ is possible if the block is orientated along a north - south axis.

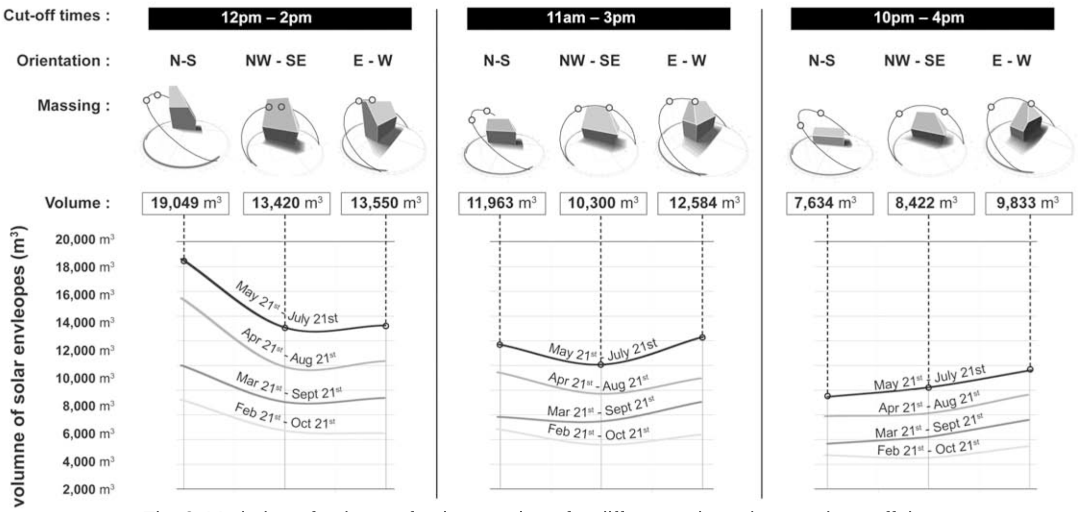

Fig. 3: Variation of volume of solar envelope for different orientations and cut-off times. Solar envelopes from the May 21st – July 21st series are shown

A number of key conclusions were established from this parametric assessment. A diagonal grid, orientated on a southwest – northeast grid, is the least efficient in terms of maximising the envelope volume, and therefore limits the density of building within this enclosing volume. This is consistent with the conclusions drawn by the Knowles study for Los Angeles [4]. A north-south or east-west grid produces higher volumes and will allow higher densities. Within these orientations, there is a sensitivity between daily cut-off times, with east-west orientations being preferable for longer daily cut-off periods and north-south for shorter daily cut-off periods. Using the Solar Envelope methodology, it is clearly possible to achieve high density development and guarantee insolation for set periods. This solar access will certainly have an amenity value, but what does it mean in terms of energy consumption?

3.4 Definition of cut-off times according to 'usefulness' of solar energy

There is good potential passive solar design in the Irish climate. With a maximum internal / external temperature difference of 12.8ºC in winter, and 950 kWh/m² of solar radiation available annually, a south facing double glazed window will gain more energy over a year than it will lose [7]. Given that space heating represents 62% of the total domestic energy requirement [8], passive solar design should form a key part of an energy demand reduction strategy.

Yannas [5] notes that *'the usefulness of heat gains released from sunshine and occupancy is strongly dependant on a building's heat loss characteristics'.* In situations where limited additional energy is required to achieve the heating set point, excessive solar radiation may not have any useful effect in terms of space heating, and can even result in overheating during summer or mid-season periods. High density developments are inherently efficient in terms of heat loss as a result of the high surface to volume ratio. This means that the 'useful' contribution that solar energy can make to space heating is diminished. Other factors which influence a building's energy balance, such as super insulation or Dublin's urban heat island [6] may also further reduce the potential for passive solar design. This presents a dilemma in terms of determining cut-off times for a solar envelope according to the usefulness of solar radiation. If an apartment is overshadowed by a building opposite, how can the shape of that building be optimised so that solar energy can make a practical difference to the space heating demand of the apartment?

In order to explore this question, dynamic simulations were undertaken using TAS (EDSL v. 9.09) to assess the thermal performance of an apartment receiving solar access only during the cut-off times as defined in the preceding solar envelope parametric tests. For the simulations, the fully internalised 65m² unit was modelled according to current Irish Building regulations for thermal transmittance, and with the majority of glazing facing south. The apartment was assumed to be continuously occupied.

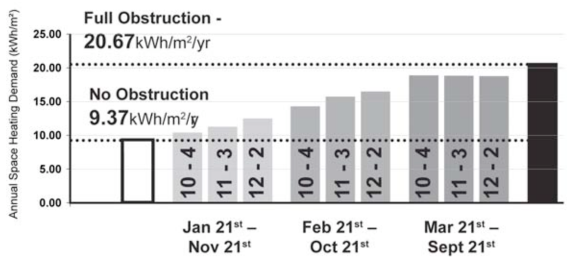

Fig. 4: Annual space heating demand with varying cut-off times for solar access

Figure 4 shows annual space heating demands for the test apartment for different daily and monthly cut-off times relative to fully obstructed and fully unobstructed conditions. The simulations demonstrate that there is a substantial reduction in the space heating demand only for the most generous cut-off times 10am to 16pm from January 21st to November 21st. For more limited cut-off times, the space heating demand is virtually indistinguishable from the fully obstructed scenario.

Therefore in order for a solar envelope to be optimised according to *useful solar* energy, extremely generous annual cut-off times have to be chosen, which allow solar access in the winter months when the sun is lowest. Clearly, high density development can not be achieved if this kind of solar access has to be achieved all the time for all apartments. The critical point, however, is that solar access does NOT have to be achieved for all apartments, at least not all at the same time.

3.5 Solar Access and occupancy patterns
The Dublin City Development Plan requires that all developments contain a range of apartment types including 1 and 2 bed units, family units, and live/work units. Two distinct occupancy patterns may be identified. Variable occupancy are typically occupied by working professionals without families, who work all day and only return home in the evenings - space heating is intermittent. Continuous occupancy units accommodate larger family units or the elderly and are assumed to have continuous heating loads given that they are occupied for most of the day,

This difference in occupancy patterns raises a very pertinent question: *Why design an apartment for solar access if no one is home?* While an argument can certainly be made for generous solar access to continuously occupied units in terms of passive solar design and amenity, it does not apply to variable occupancy apartments which are vacant throughout the day. This observation is taken as the starting point for the site massing strategy for the Cork Street site.

3.6 Site massing strategy on Cork Street Site
The design proposal is divided into five main blocks. Blocks A, B, C & D accommodate variable occupancy units and are laid out on a north-south axis where they receive morning and evening solar access from the east and west. This solar access will have an amenity value but no value in terms of its useful contribution to the apartments' space heating loads. Continuous occupancy units housing families and the elderly are accommodated in Block E which is aligned along an east west axis, facing south for maximum solar access. Continuous occupancy units are also positioned on the top floors of Blocks A, B, C & D where obstruction may be minimised. Using this basic site layout strategy, individual blocks may then be chamfered to achieve solar access to the apartments they overshadow during periods when that solar access is useful. Figure 5 shows how three separate chamfers are used to achieve this access, each defined by particular cut-off times.

The first chamfer achieves solar access from 10am to 6pm, between January 21st - November 21st to the continuous occupancy apartments in the South facing Block A. The second chamfer achieves evening solar access to the East – West facing variable occupancy units between April 1st to September 30th from 4pm onward. This access will have an amenity value when the occupants return from work, but will not influence the space heating demand. The third and final chamfer optimises the geometry of the top floor continuous occupancy units from 10am - 6pm, between January 21st - November 21st. This chamfering also reduces westerly obstruction to the variable occupancy units below, thereby further improving evening solar access.

The resulting urban massing represents the maximum volume of development according to the shadow fences and cut-off times selected. The site layout strategy also insures that central public area is never fully in shade as the sun passes to the south and shines between the blocks A, B, C & D.

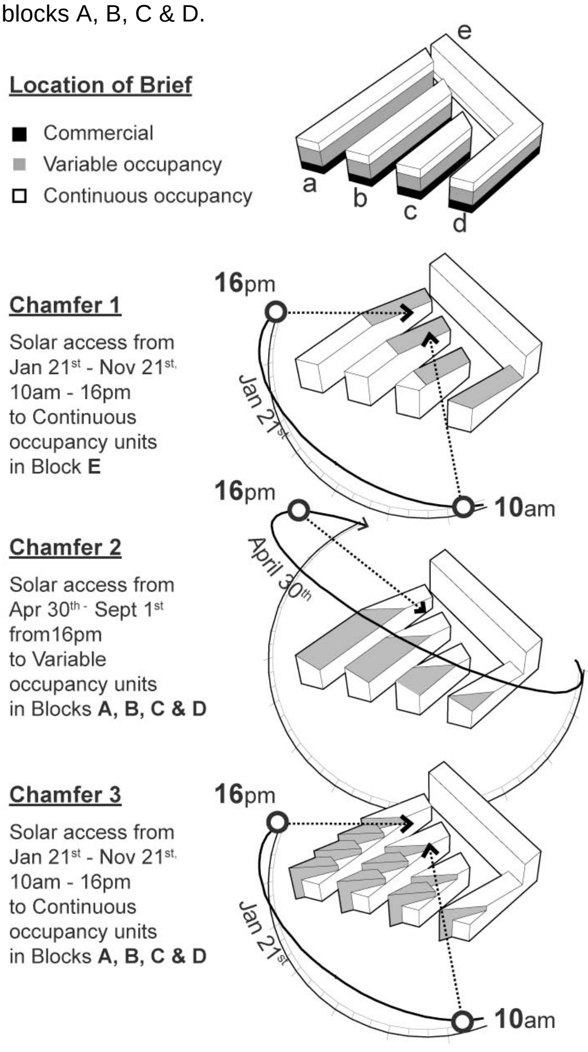

Fig. 5 Chamfers used to provide solar access to units according to occupancy patterns

4.0 Optimising the benefits of solar access at the building scale

The second phase of the design research investigated how the individual apartment units in the design proposal could benefit from the solar access achieved through the site massing strategy.

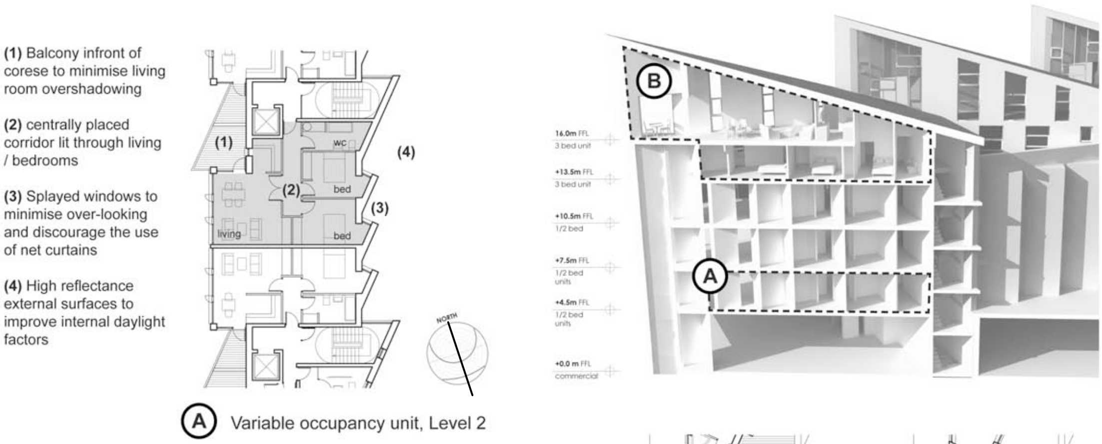

Fig 6: Block B: Apartment plans and perspective section

4.1 Daylighting / sunlight in Level 1 variable occupancy units

The site massing, developed according to solar geometry, also offers benefits to daylighting under overcast conditions, with reduced obstruction to ground floor units, and therefore an increased sky view. A detailed analysis was undertaken on the most obstructed units in the lower floors of blocks A, B. C & D, to improve the luminous environment within these units.

Figure 6 summarises the strategies adopted. Balconies, provided in order to meet private open space requirements, are located in front of the cores so that the living spaces are not overshadowed (1). A centrally placed corridor is day lit via glazed doors in the living room and bedroom, also allowing cross ventilation when required (2). The glazing of the bedroom windows is splayed to eliminate overlooking between adjacent blocks, and therefore discourage the use of net curtains (3). Higher reflectance materials are used on the ground plane to increase the external reflected component to the ground floor units which have limited sky view (4). Through these strategies, illuminance levels within the lowest apartment were improved to 375 lux in the living room, 175lux in the bedroom, and 75lux in the corridor.

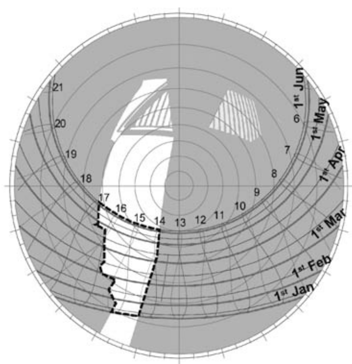

Fig. 7 : Stereographic projection of annual solar access to Level 1 variable occupancy unit – dotted line indicates hours of solar access

Solar access to these apartments was also proven at this stage. Figure 7 shows annual solar access to the Level 1 living room window in stereographic sunpath projection. The apartment always receives direct sunshine throughout the year with a maximum of four hours in June. This represents the worst case scenario, with solar access improving for higher level units.

4.2 Thermal performance of Levels 5 & 6 continuous occupancy units

Unlike the internalised intermittent occupancy units, the top floor continuous occupancy units on Blocks A, B, C & D (fig. 8) have a greater potential for passive solar design, given their high exposed surface area and heat loss, and unobstructed solar access throughout the year. The second stage of the design development focussed on this potential, with a view to achieving 15 kWh/m²/annum space heating demand for these apartments as per the PassivHaus standard. Figure 10 shows the iterative steps by which this space heating benchmark was achieved. All dynamic thermal simulations were undertaken using TAS. The base case condition assumed minimum Part L standards, and the plan geometry as shown in Figure 9, and as derived from the urban site massing strategy.

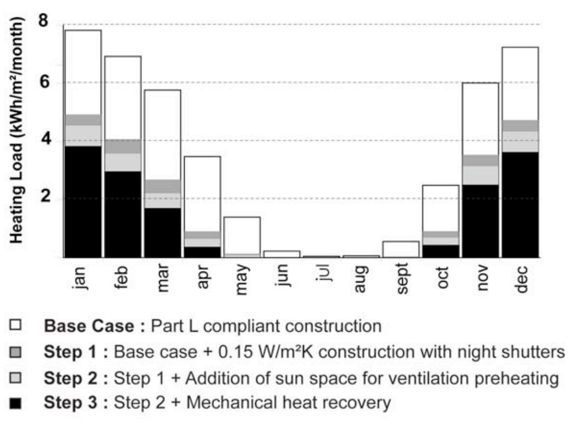

Fig 10: Monthly space heating demand for top floor continuous occupancy unit showing iterative improvements to reduce the space heating demand to within PassivHaus standards

Of the iterative steps explored, improvements to the building fabric and mechanical heat recovery were found to have the greatest impact on the space heating demand. Passive solar strategies such as the optimisation of the window ratio and the integration of a passively heated sun space through which the main apartment is ventilated also had a measurable impact, although to a lesser degree. It is noted that non optimal orientation of the sun space, the high volume, and minimal coupling to the parent building, all contributed to this poor performance. Through these combined measures however, the annual space heating demand was lowered from 47 kWh/m²/annum for the base case scenario to 15 kWh/m²/annum. Overheating within the top floor apartment was also assessed within the sunspace. TAS simulations demonstrated that the space was susceptible to overheating during the summer months, however through the use of internal blinds, and natural ventilation, the number of hours over 28ºC was reduced to 14.

4.3 Integration of Solar Renewables

Figures from SEI [8] suggest that hot water accounts for 23% of all domestic electricity consumption, and lighting a further 18%. The site massing strategy derived to achieve solar access to individual apartments also enables parts of the buildings for the integration solar renewable technologies such as solar thermal panels and photovotaics. The façade of Block E, guaranteed solar access throughout the year, was developed to explore how this integration migh influence the architecture. PV and solar thermal panels were sized to meet the hot water demand and the estimated electricity demand for lighting for Block E only. The impact of these additions was then measured in terms of the potential reduction in CO_2 relative to grid supplied electricity from the coal powered power plant in Poolbeg, Dublin. It was estimated that with 170m² of solar thermal panels and 400 m² of PV panels a 43% reduction in CO_2 could be achieved.

5.0 Conclusions

The final scheme comprises 121 residential units, and 2,600 m² of commercial space. The total built density as expressed as a plot ratio is 2.45. This figure is lower than the Development Plan maximum value of 3.00 for inner city sites, but is still high for a low density city like Dublin. Clearly, a higher density could have been achieved by reducing the hours of solar access. In this project, cut-off times were defined according to the usefulness of solar access in terms of the potential for reducing the space heating demand. The validity of this approach could be critiqued in terms of the limited contribution that solar energy can make in the thermally efficient apartment typology, however additional benefits such as improved daylighting and the potential for active solar renewables justify the selection of generous cut-off times.

Perhaps the most significant benefit of a site massing strategy derived from solar geometry is not in terms of energy savings but rather improved amenity. The psychological value of solar access cannot be understated in a climate such as Ireland's. In the proposed development, apartments and outdoor public spaces are assured solar access throughout the year during defined periods. This is a critical factor in challenging the typically negative perception of high density inner city developments, normally associated with lack of privacy, noise and over-shadowing. A high density scheme which does not suffer from these shortcomings, will offer a far more attractive option for house buyers, and may play a significant role in redefining Dublin as a high density city.

6.0 Acknowledgements

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7.0 References

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