# 4.2 ROOFTOP "GREENING" AS AN OPTION FOR MICROCLIMATIC AMELIORATION IN A HIGH-DENSITY BUILDING COMPLEX

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## 1. INTRODUCTION

Urban form can broadly be characterised as a three-dimensional field bounded by four attractors: high density high-rise; low density high-rise; low density low-rise and high density low-rise – or respectively, the "Hong Kong", "Le Corbusier", "Dallas" and "Old Europe" models. The United Nations forecasts that by 2025, 60% of the world's population will live in urban areas compared to 29% in 1950. Urban growth is a given; the only variable is which attractor will dominate (Figure 1).

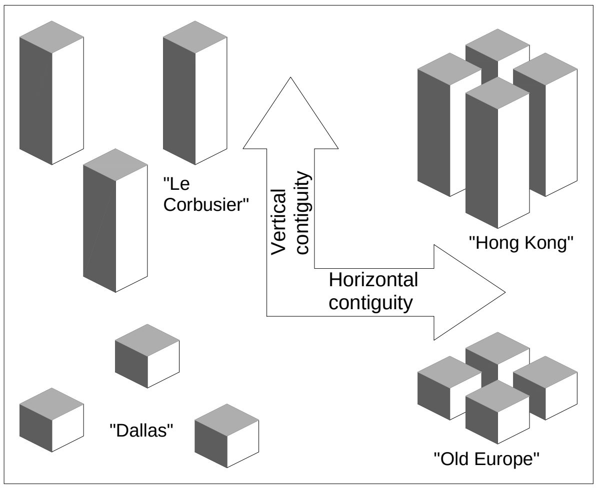


*Figure 1: The four attractors of urban form.*

It is widely (though not universally) held that "compact" cities – high density and low-to-medium-rise – are more environmentally sustainable (Jenks *et al*, 1996), particularly through reducing the environmental impacts of transportation and encroachment on non-urban land. However, such benefits are not penalty-free. Urban air temperature and wind speed are affected by changes in the radiation balance of dense urban spaces, by convective heat exchange between ground, buildings and atmosphere, and by heat generation within the city itself (Givoni, 1998). The hydrological cycle is short-circuited by the predominance of impervious surfaces (Hough, 1989). Air pollution trends reflect energy patterns across cities (Alberti, 1996); hence reduced motor vehicle pollution following densification may be negated by increased emissions from electricity generation – e.g. for air-conditioning to counter urban heat island effects. Finally, ecosystem structure and function changes markedly along the rural-urban gradient (McDonnell and Pickett, 1990).

The role of urban vegetation in addressing these diverse impacts is well documented (Hough, 1989; Beer and Higgins, 2000). Givoni (1991; 1998) details a range of bioclimatic benefits including reductions in solar and long-wave heat gain, wind speed and air pollution.

The denser the city, the fewer the opportunities to ameliorate the adverse impacts of densification through conventional approaches to urban "greening" (street trees, parks and gardens). Bruse and Skinner (2000) observed that as building density increases, the radiatively active surface moves upward to the urban roofscape. Rooftops represent an under-utilised resource for greening the compact city, an option which can only be reinforced by the fact that much of the city's microclimatically significant absorption, reflection and emission of radiation occurs there.

This study models the microclimatic effects of a major new development at a university campus in Sydney, Australia, with and without the introduction of rooftop vegetation. The findings are evaluated in relation to outdoor thermal comfort and building performance. Additional environmental aspects of roof greening are discussed, and the implications considered from the perspective of connecting teaching and research with the physical fabric and operation of the campus, as well as the broader dimension of urban sustainability.

## 2. SITE AND CONTEXT

The University of New South Wales (UNSW) is a major teaching and research institution located six kilometres from the Sydney CBD, accommodating about 26,000 equivalent full-time students and more than 4000 staff. The 35 hectare campus is spatially constrained by abutting land uses, hence growth and intensification of the University's activities have necessitated a corresponding densification of built form.

The study site includes part of the University's main pedestrian mall, current and proposed multi-storey buildings, outdoor eating and grassed passive recreation areas, and paved roads, paths and car parking spaces (Figure 2). Existing buildings range from 12 to 47 metres in height. Approximately 76% of the 37,500 $m^2$ study site is currently covered by impervious surfaces (paving and roofs), which will increase to 80% on completion of the new buildings.

Existing vegetation includes several areas of lawn, a variety of native evergreen and exotic deciduous trees (e.g. *Eucalyptus*, *Ficus* and *Populus* spp.) generally 10 to 15 metres tall, and shrubs and groundcover plants in beds abutting buildings and car parking spaces.

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The urban geometry of the site and proliferation of hard surfaces clearly have a marked effect on the local microclimate, outdoor thermal comfort (particularly in Sydney's hot humid summers) and building energy performance, although evidence is largely anecdotal.

The planned development comprises a new Law building of four storeys (18 m) with a footprint of 3500 $m^2$ and two internal courtyards opening at second floor level (8 m), and an Analytical Centre ranging from three to five storeys (15-24 m) with a 1150 $m^2$ footprint which "wraps" around the existing Applied Science building.

*Figure 2: The study site – new buildings shown in cyan.*

UNSW has developed a strong sustainability profile in its teaching, research and operations, including the promotion of synergies between environmental learning and the learning environment of the campus itself. There is growing interest within the UNSW Built Environment Faculty in the topic of roof gardens, with the University's own predominantly flat rooftops seen as potential case studies for research and learning. Hence this study aims for practical utility both educationally and through informing campus development.

## 3. METHODS

A three-dimensional non-hydrostatic model, ENVI-met, (Bruse and Fleer, 1998; Bruse, 2004) was used to simulate the microclimatic effects of the UNSW building redevelopment with and without the introduction of vegetation (where structurally feasible) on the rooftops of the two planned and two existing buildings within the development zone.

ENVI-met was designed to analyse surface-plant-air interactions at the microscale, with a typical horizontal resolution of 0.5-10 metres. Model calculations include short-wave and long-wave radiation fluxes with respect to buildings and vegetation; evaporation, transpiration, and sensible heat fluxes from vegetation; surface and wall temperatures; soil water and heat exchange; PMV values; and particulate pollutant dispersal (Bruse, 2004).

Three simulations were carried out: existing conditions; with new buildings; and new buildings plus rooftop vegetation. Table 1 outlines the specifications used to model the rooftop planting, and Table 2 lists the main model input parameters. Planting was selected on the basis of roof structural engineering constraints.

| Building | Planting |
|---|---|
| Law Building | 2 x 10 m trees in each courtyard; "checkerboard" pattern of 2 m shrubs and grasses on roof, representing native coastal vegetation |
| Analytical Centre | Dense 2 m shrubs on western (lower) section of roof; 50 cm grasses on eastern section |
| Dalton Building (directly east of Analytical Centre) | Dense 2 m shrubs (native heathland vegetation), 15 m building |
| Heffron Building (directly north of Dalton Building) | 50 cm grasses (representing native grassland), 24 m building |

*Table 1: Rooftop planting selected for the simulation.*

| | |
|---|---|
| Location | $33.9^{o}$ south, $151.2^{o}$ east |
| Date and time of simulation | 21/01/03, 0600 - 1800 |
| Wind speed and direction | 5 m/s at 10 m above surface, from $135^{o}$ |
| Initial air temperature | 292K |
| Specific humidity at 2500 m | 8 g/Kg |
| Initial soil temperature (upper layer) | 295K |
| Albedo walls | 0.4 |
| Albedo roofs | 0.3 |
| Cloud fraction | 25% mid-level cloud cover |
| Grid dimensions and spacing | 50 x 30 x 24 at 5m grid size |

*Table 2: Some key input values for the study site.*

## 4. RESULTS

ENVI-met generates extensive data across a wide range of atmospheric, surface, soil and vegetation properties on the basis of user-selected time steps. The main variables of interest for this study are wind speed and air temperature. A January mid-afternoon (14:00 hours) "snapshot" was selected, representing a time when more people are likely to be on campus and the ambient temperature is likely to be close to the daily maximum.

### *4.1 Wind speed*

The model suggests the new development will have a significant effect on the wind regime in the study area (Figure 3). The area between the Applied Science, Heffron and Dalton buildings (top right) at present can be quite unpleasant in windy conditions, and similar impacts on pedestrian comfort are predicted for the space between the new Law building and Applied Science (centre of Figure 3b).

Rooftop vegetation has an insignificant effect on wind speed at 2 metres above ground level, as would be expected from the modest scale of the planting. However, a small reduction in wind speed at rooftop level was observed.

*Figure 3 a (top) and b: Existing wind conditions (a), and after redevelopment (b). Wind is from 135°. For visual clarity existing vegetation is not shown*

### *4.2 Air temperature*

The model predicts a small (0.2 K) temperature increase in the car park area to the north of the new buildings (top centre of Figure 2) following construction.

The influence of rooftop greening on air temperature is negligible beyond the immediate environs of the planted roofs, where maximum reduction is 0.5 K. Figure 4 shows a horizontal section at 15 metres, the height of the rooftop planting on three of the four greened buildings. The eight colour steps from blue to magenta represent 0.04° K intervals.

## 5. DISCUSSION AND CONCLUSIONS

The UNSW campus is morphologically close to the "Le Corbusier" archetype shown in Figure 1, with the proviso that the architect envisaged high-rise urban form within grassed parkland, while the University groundplane is extensively paved. Within such a framework, the present study suggests that the benefits of small-scale rooftop greening in ameliorating outdoor thermal comfort are practically restricted to the immediate rooftop level vicinity of the planted areas.

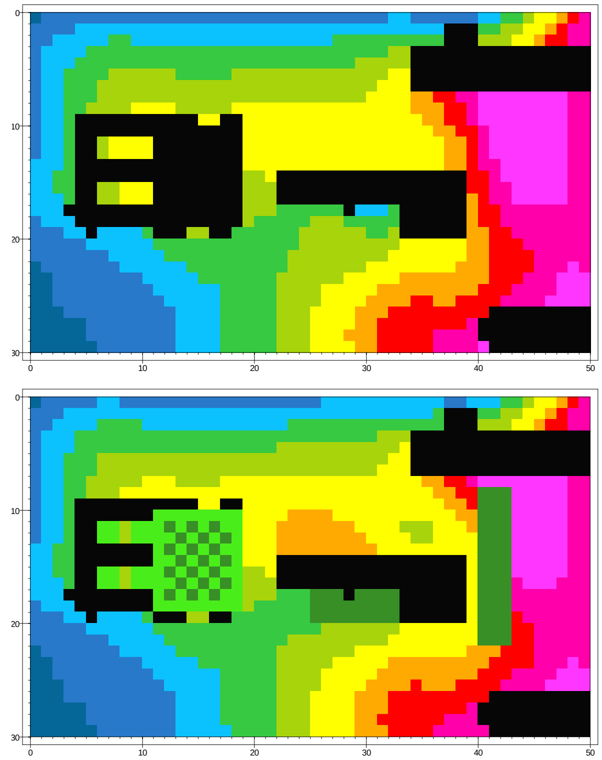

*Figure 4 a (top) and b: Buildings without (a) and with rooftop planting, x-y section at 15m; blue = <295.6 K, magenta = >296 K.*

While this is may be beneficial where roof gardens are accessible to building occupants, the limited influence of modest roof greening on urban microclimate in "semi-Corbusian" sites suggests that if outdoor thermal comfort is a major design objective, a combination of strategies is required.

Sites such as university campuses, high-rise residential estates and business parks must deal with considerable pedestrian traffic and pressure to accommodate motor vehicles. Paved surfaces provide the conventional solution. Alternatives with more optimal microclimatic outcomes include use of pervious paving materials and extensive planting coupled with vehicular traffic and parking demand management.

Bruse and Skinner (2000) found a reduction in air temperature of up to 1.4 K above the vegetated roof surfaces in their model. Temperature reduction was mainly restricted to the roof locations, subject to some advection with the prevailing wind. It appears likely that the significant differences with the results presented here reflect the dissimilarity in urban form between the two sites, particularly with respect to building height. Bruse and Skinner's Melbourne site comprised more closely spaced low-rise (3-11 m) buildings, with very little existing vegetation, whereas despite the prevalence of paved surfaces, the UNSW campus is relatively well treed. Moreover, the Melbourne model included the greening of all roofs in the study area, representing 45% of the site, compared to 15% green roof coverage for the UNSW site.

The environmental advantages of rooftop greening are not, however, restricted to improving microclimate. Useful summaries are provided by Osmundson (1999) and Peck *et al* (1999), and an extensive review in Bass and Baskaran (2003). A substantial research project conducted by the latter authors demonstrated a 75% reduction in stormwater runoff from a "meadow" roof garden with a 150 mm soil layer compared to an ungreened control roof. Building energy demand for space conditioning during the Canadian summer was reduced from 6.0-7.5 kWh in the control building to 1.5 kWh in the greened building, through direct shading, evaporative cooling from the plants and the bonus insulation provided by the plants and growing medium (Bass and Baskaran, 2003).

Additional benefits discussed in Peck *et al* (1999) include: improved air quality due to the ability of vegetation to filter particulate and some gaseous pollutants from the atmosphere; biodiversity conservation; increased green amenity space in crowded urban conditions; aesthetic pleasure in observing nature in the city; and economically, improved property values and employment opportunities. Lifecycle costing of building projects – i.e. with respect to HVAC capital costs and operational energy management – has also identified net financial savings.

To date the majority of research on roof greening has occurred in Europe and to a lesser extent, North America. There is an obvious need for more work relevant to warm temperate, subtropical and tropical climate zones. There is also a need for further modelling of the microclimatic effects of green roofs in different urban spatial typologies. Morphological aspects of urban environmental performance are crucial to understanding – and designing – more sustainable cities (Adolphe, 2001), and green roof research is a key part of this.

It can be argued that at a time of mounting evidence of the negative impacts of unsustainable economic growth on the global environment, universities have a particular responsibility both to help define, and to become exemplars of, environmental best practice. Awareness is growing that universities can effectively teach and demonstrate the theory and practice of sustainability through taking action to understand and reduce the unsustainable impacts of their own activities (Leal Filho, 2000), thereby helping to overcome the paradox of teaching sustainability in unsustainable surroundings. From this perspective campus rooftop greening would seem to provide an ideal opportunity to combine transdisciplinary environmental teaching and research with a visible commitment to "walking the talk".

The role of environmental exemplar extends beyond connecting teaching and research with the physical fabric of the campus, to incorporate a systematic engagement with the wider community. Linkage of curricula, campus fabric and community engagement under the aegis of environmental education for sustainability (Tilbury, 2003) can create a powerful transformative agenda based on the nexus between theory and practice. Rooftop greening can certainly play a role in this process.

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