MICRO-CLIMATE MODIFICATION AND POTENTIAL FOR REDUCTION IN SUMMERTIME OVER-HEATING IN SOCIAL HOUSING, SOUTH WALES (UK)

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ABSTRACT

There is a growing consensus that the climate is changing faster than at any time in the past millennium. This is likely to have major effects upon many aspects of the built environment. UK Climate Impact Projections 09 indicate significant increases in Summer Mean Temperatures. This may suggest a requirement for cooler buildings during the summer months. In consequence, that would likely lead to an increase in demand for mechanical ventilation and comfort cooling. In the UK, the energy balance used in modifying environmental conditions could change from one predominantly concerned with winter heating, to a situation in which more energy is used to provide summertime cooling.

This paper reports a research project, funded by the European Union Social Fund, in collaboration with United Welsh (Housing Association).The project aims to develop guidance for low carbon and ecological social housing in South Wales and is concerned with design and construction. Evidence already suggests recently constructed dwellings are overheating even now, under current summertime conditions. With a possible life span in excess of sixty years, they must be suitably adapted for changed climatic conditions, if they are to remain fit for purpose throughout. With the prospect of a Mediterranean type climate, external spaces around dwellings will become more important as levels of outdoor activity increase. The psychological benefits of green space, and its amenity value to residents is well recognised. Some innovative approaches to surface water management and enhancement of biodiversity focus upon the benefits of external landscaping. This research investigates whether a better understanding of how such factors influence the local micro-climate could deliver benefits in terms of improved internal conditions, and reduced energy use.

The methodology adopted takes a recently completed new-build social housing scheme from the portfolio of the industrial partner, and using recognised thermal modelling packages, seeks to establish if, and to what extent summertime overheating is currently an issue, and how this may be impacted by climate change. Utilising 'ENVI-met', a micro-climate simulation model, notional changes in the form of specific landscape measures are then assessed in terms of their influence upon the local environment. This data is finally used in a further iteration of modelling, to evaluate the impact of micro-climatic modification and ventilation strategies on the internal environment of adjacent dwellings.

This paper will be useful to Registered Social Landlords, Local & Regional Government Agencies, and Private Sector organisations engaged in the planning, design and procurement of residential buildings.

KEYWORDS

Adaptation, Climate Change, Overheating, Micro-climate.

1 INTRODUCTION

There is a growing consensus that the climate is changing faster than at any time in the past millennium, and that further change is inevitable. This is likely to be long-lasting and have a significant impact on the built environment (IPCC, 2007). UK Climate Impact Projections 09, indicate possible increases in Summer Mean Temperatures for South Wales (UK), of 2-3°C by the middle of the century (Met Office, 2010). This suggests a requirement for cooler buildings during the summer months, and would likely lead to an increase in demand for mechanical ventilation and comfort cooling. In the UK, the energy balance used in modifying environmental conditions could change from one predominantly concerned with winter heating, to a situation in which more energy is used to provide summertime cooling (Gething, 2010).

With the prospect of a Mediterranean type climate, external spaces around dwellings will become more important as levels of outdoor activity increase. The psychological benefits of green space and its amenity value to residents is well recognised (Winson, 2011). In the UK, the 'Oil Crisis' of the 1970's provided the stimulus for research activity aimed at energy conservation and demand reduction. The principle of utilising external landscape measures was identified as a passive approach to the design of energy efficient buildings (BRE, 1990). Political and economic changes however, resulted in a reduction in the perceived threat to national fuel security, and interest in this alternative approach declined.

This paper reports a research project, funded by the European Union Social Fund, in collaboration with United Welsh (Housing Association). The project aims to develop guidance for low carbon and ecological social housing in South Wales and is focussed upon adaptation measures in relation to micro-climatic modification. Current U.K. standards largely focus on reducing heating demand. Evidence suggests that recently constructed dwellings are overheating even now, under current summertime conditions (NHBC, 2012). With a possible life span in excess of sixty years, these dwellings must be suitably adapted for changed climatic conditions, if they are to remain fit for purpose throughout their lifecycle. Predicted demographic changes also suggest higher levels of vulnerability to excess heat, as an aging population begins to exhibit increases in long term health conditions and increased susceptibility to heat stress.

Using contemporary modelling techniques this research investigates whether a better understanding of how such measures influence the local micro-climate could deliver improved internal conditions, and reduced energy use.

The methodology adopted looks at a recently completed new-build social housing scheme from the portfolio of the industrial partner. In the first part of a two-stage modelling process, 'ENVI-met', a micro-climate simulation modelling platform (Bruse, 2010), is utilised to assess the impact of specific landscape components. Solar shading, and localised air temperature data are then used to produce amended Energy Plus weather files. In the second part, natural ventilation simulations, using DesignBuilder, a computer based thermal modelling package (Designbuilder, n.d.) are completed using weather files edited to reflect output data from stage one. Results are analysed to assess the impact of micro-climatic modification upon the ventilation and internal temperatures of domestic living space within the dwelling.

2 METHODOLOGY

2.1 Case Study: Unit 5, Heol Elan, Rassau, Ebbw Vale.

A 5 person, 4 bedroom, detached, south-facing dwelling was selected as the basis for this case study. Constructed in 2010, and built using lightweight timber frame construction, to Code for Sustainable Homes Level 4. The detached nature of the property provides the greatest ratio of external wall to floor area, and likely to most clearly demonstrate the impact of external conditions.

2.2 ENVI-met

2.1.1 Area Input File

A notional layout was utilised in the Area Input File (AIF), and built around a 1m^2 grid. The geographic location was designated as latitude 51.80137, longitude -3.224734 (junction of Honeyfield Road and Glyndwr Road). The dwelling footprint is represented by a rectangular plan form 8m x 8m, and a total plot area of 240 m^2, (12m wide and 20m deep). The front bay window was simplified, and the roof assumed to be flat, to accommodate limitations within the model. The overall building height was designated as 7m. Distances to boundaries were representative of average plot sizes within the development, with a distance of 2m to side boundaries and 6m from the front and rear facades. In the first of two area input layouts, ground treatment is limited to two surface types. A paved concrete hard-standing, sized to accommodate one parked vehicle within the front garden area, and concrete paving along the side elevation to the rear access door, were also included. The remaining ground surface was assigned to 'grass'. To account for the impact of adjacent units the basic plan was repeated to each side, giving an overall grid size of X=36 Y=20. A telescoping vertical grid was employed, consisting of 9 modules to the top of the 3D model (Z=9). A number of 'receptors', capable of sensing and recording model data at a specific point were referenced and located at strategic points around the building perimeter.

2.1.2 Configuration Input

Input data specified a 24 hour period for the total simulation time with a start time of 04:00 to allow for initialisation prior to sunrise. The simulation date 21.06.2002 was assigned to provide maximum sun altitude, and to align the data output with Designbuilder, for use in the second stage of the process. Input data for wind speed, wind direction, initial temperature, specific and relative humidity were specified as daily average values taken from the Prometheus current weather file for Cardiff (Exeter University, n.d.). Initial temperature and specific humidity were calculated using a constant value for atmospheric pressure of 1027 hPa. A Roughness Length of 1.0 was considered to be an appropriate value for a suburban area with regular large obstacle coverage.(DWIA, n.d.). Configuration data as Table 1.

Table 1: Configuration Input File data

Input	Value	Unit	Input	Value	Unit
Start Simulation at Day	21.06.2002	DD.MM.YYYY	**[SOILDATA] Settings for Soil**		
Start Simulation at Time	04:00:00	HH:MM:SS	Initial Temperature Upper Layer (0-20 cm	293	K
Total Simulation Time	24.00	Hours	Initial Temperature Middle Layer (20-50 cm)	293	K
Save Model State	60	min	Initial Temperature Deep Layer (below 50 cm)	293	K
Wind Speed in 10 m ab. Ground	7	m/s	Relative Humidity Upper Layer (0-20 cm)	50	%
Wind Direction (0:N,90:E,180:S,270:W)	246		Relative Humidity Middle Layer (20-50 cm)	60	%
Roughness Length z0 at Reference Point	1.0		Relative Humidity Deep Layer (below 50 cm)	60	%
Initial Temperature Atmosphere	284	K	**[TIMESTEPS] Dynamical Timesteps**		
Specific Humidity in 2500 m	5.69	g Water/kg air	Sun height for switching dt(0) -> dt(1)	40	
Relative Humidity in 2m	73	%	Sun height for switching dt(1) -> dt(2)	50	
Database Plants	[input]\Plants.dat		Time step (s) for interval 1 dt(0)	2.0	
[BUILDING] Building properties			Time step (s) for interval 2 dt(1)	2.0	
Inside Temperature	293	K	Time step (s) for interval 3 dt(2)	2.0	
Heat Transmission Walls	0.29	W/m²K	[PMV] Settings for PMV-Calculation		
Heat Transmission Roofs	0.16	W/m²K	Walking Speed	0.0	m/s
Albedo Walls	0.3		Energy-Exchange	58	Col. 2 M/A
Albedo Roofs	0.25		Mech. Factor	0.0	
[PLANTMODEL] Settings for plant model			Heat transfer resistance cloths	0.5	
Stomata res. approach (1=Deardorff, 2=A-gs)	2				
Background CO2 concentration	350	ppm			

The internal temperature was specified as 293K (22°C) and maintained throughout the simulation period. Thermal transmission values for walls and roof were taken from specification by Stride Treglown (architects), and albedo ratings for external facing materials taken as mid-range values published by NASA (National Aeronautics and Space Administration, 1999). Values for 'Timestep Intervals' were reduced to 2.0 to increase model stability. Following completion, data output from the ATM (atmosphere) files was imported in to Leonardo (information visualisation software) for analysis, and sense checking. The DesignBuilder 'Sun Path Tool' was used to evaluate MRT (mean radiant temperature) output to ensure model behaviour was in line with expectations. Data output from receptors was checked against output from the main ATM files and used to check model performance in the vertical plane (Z axis).

2.1.3 Suburban scale garden trees

A second area input file was created, based upon the original layout and incorporating 13 standardised trees. A deciduous, 6.5 m high 'Field Maple' (acer campestre) was selected for suitability in terms of size, crown/root spread, tolerance of variable soils, exposure and local conditions (Cardiff City Council, 2013). A local specimen was identified and surveyed using a calibrated surveying staff, ranging rods, tripod mounted Leica D5, laser distance meter, and Canon Eos 400D digital SLR camera. A modification of the photographic technique introduced by Peper and McPherson (1998), and later developed by Shinzato and Duarte (2012) was used to calculate the Leaf Area Index (LAI). This was converted into ten values for Leaf Area Density by re-scaling profiles established by Spangenberg, Shinzato et al. (2008). This data was used to define the modelled tree within the database. Two trees were allocated to each front garden, positioned 5m apart, at a distance of 5m from the front and rear facades. A row of trees, 5m apart was positioned along the northern boundary. All other variables remained consistent with those originally specified, and formed the basis of the second simulation of stage one.

2.1.4 ENVI-met output

Data output from both simulations was interrogated using Leonardo. Horizontal sections for Z=1, at hourly intervals throughout the simulation period, were evaluated and compared. Output for this level (1.5m above external ground level) was selected as representative of conditions likely to be experienced by a pedestrian within the model space. MRT was selected as an appropriate parameter for analysis. The process of temperature scale selection indicated that values for MRT were higher than expected. Guidance literature suggested over estimation of solar radiation, to some degree, was a recognised characteristic of the ENVI-met model. Future iterations could include the application of a solar correction factor. In this study, comparative analysis of relative values is adopted. The range and bandwidth of temperatures were adjusted to provide clarity of detail to areas and time-frames of particular interest. Standardised field maple trees, were also added to the DesignBuilder model. Using the 'Sun Path Tool', shadow analysis was completed to produce rendered images as a further basis for comparison. Vertical sections taken through the model at X=15 were also analysed to investigate temperature distribution in the vertical plane.

2.3 Impact on internal environment

To determine if, and to what extent, modification of the external micro-climate, by the planting of suburban scale trees impacts upon environmental conditions within the dwelling, it was necessary to link the ENVI-met outputs to a process of internal modelling. In a two-stage simulation study on a residential building in Cairo, reported by Famy, Sharples and Eltropolsi (2009) average data output from a series of receptors within an ENVI-met model is used to amend EnergyPlus weather files, in turn used for internal thermal simulation of a single zone domestic dwelling. For the purposes of this study, a similar approach has been adopted and modified to investigate an individual ground floor living space within a multi-zone dwelling, and in the context of a northern European climate.

2.4 Amended Energyplus Weather Files

Drawings and specification for the dwelling were utilised to generate a three dimensional 'zoned' model in DesignBuilder. The lounge, a single, ground floor living space, is selected as the focus of study, and amended EnergyPlus weather files are created for each scenario and for use in simulating the environment within this zone. Output for level Z=1 from ENVI-met receptor R5, located immediately adjacent to external window W1, is used to modify climatic data held within the standard current weather file for Cardiff. Modified parameters include, air temperature, relative humidity, dew-point, short-wave direct solar radiation, short-wave diffuse solar radiation, and global horizontal radiation. Separate files are created for simulating internal conditions within the zone, and tagged to identify each scenario (ground cover with and without trees), zone, receptor, z value, and simulation date.

2.5 Natural Ventilation Simulations

For each scenario, the relevant amended weather file was loaded, and natural ventilation simulations completed. Graphical outputs and numerical data were exported as .wmf and .csv files for analysis and comparison, and the CFD capability within Designbuilder utilised to interrogate the output data. Slice and variable settings were adjusted to enable analysis of different parameters, with adjustment of value ranges and band widths as necessary to access detailed information and assist interpretation.

3 RESULTS

3.1 Stage One: Comparative analysis of ENVI-met Simulations (Figure 1.)

Results for the simulation based upon ground cover only are compared with those in which field maple trees were added. Micro-climatic conditions are evaluated and the impact of upon the external area is analysed by reference to differential MRT values as observed at time-frames throughout the simulation period and to corresponding solar shadow analysis.

3.2 Stage Two: Comparative Analysis of Natural Ventilation Simulations

The graphical output from DesignBuilder natural ventilation simulations for scenario AL3 (based upon weather conditions modified to include data output from the ENVI-met simulation for 'ground cover only') and AL6 (based upon external conditions modified by the addition of field maple trees.) is analysed to assess the effective air movement, in terms of in-flow and out-flow through individual openable windows..

3.2.1 Temperature Distribution (Figure 2.)

In accounting for radiant influences, analysis of internal temperature distribution concerns values for both operative and air temperatures. Interrogation of output for 15:00 hours on 21.06.2002 is taken as the basis for analysis. Plan view CFD slices taken at floor and cill level, and cross-sectional slices at W1 and W4, analysed using filled temperature contours, suggest the room in simulation AL6 is significantly cooler than in simulation AL3.

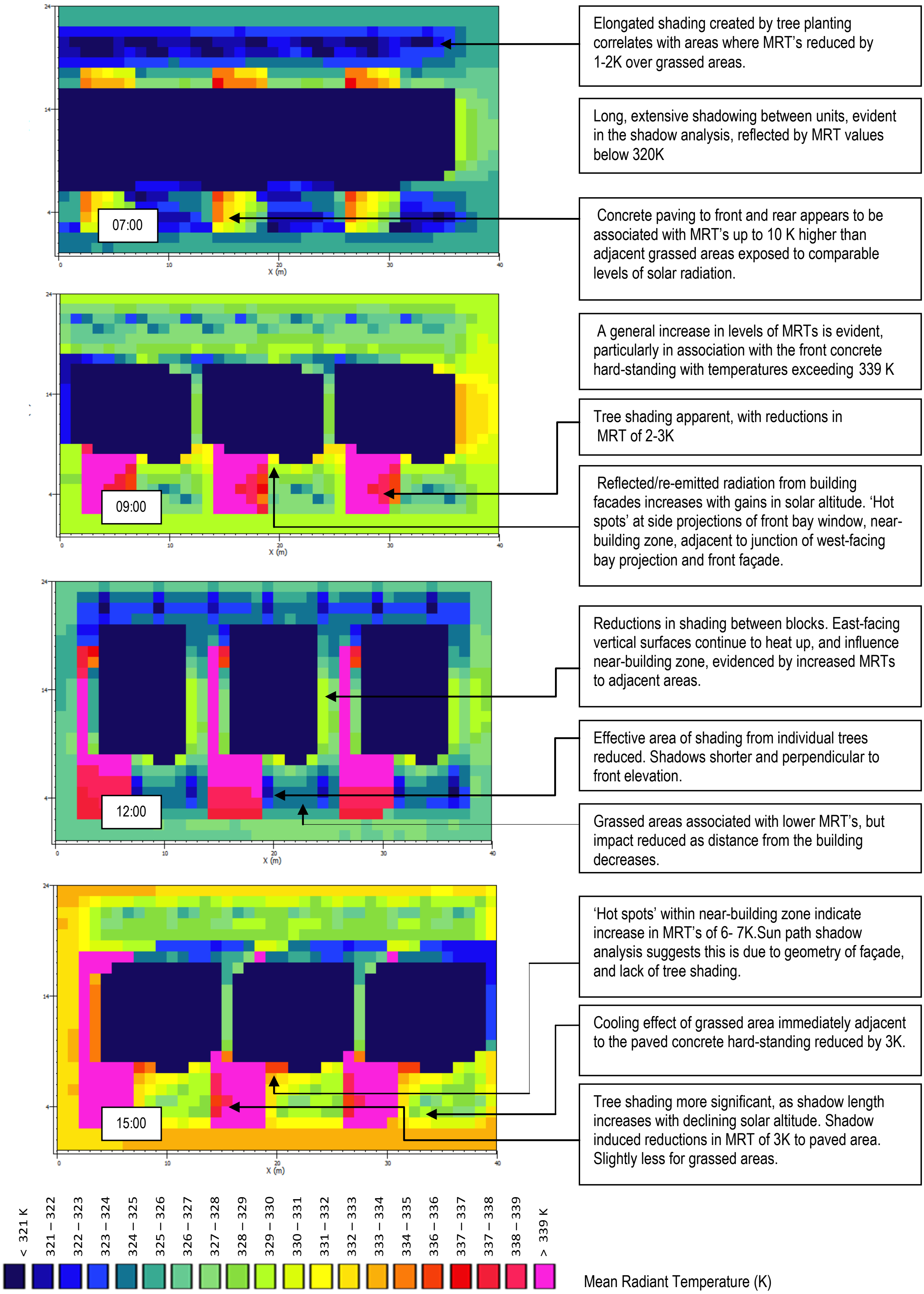

Figure 1. Analysis of ENVI-met Output for Simulation with Field Maple TreeS

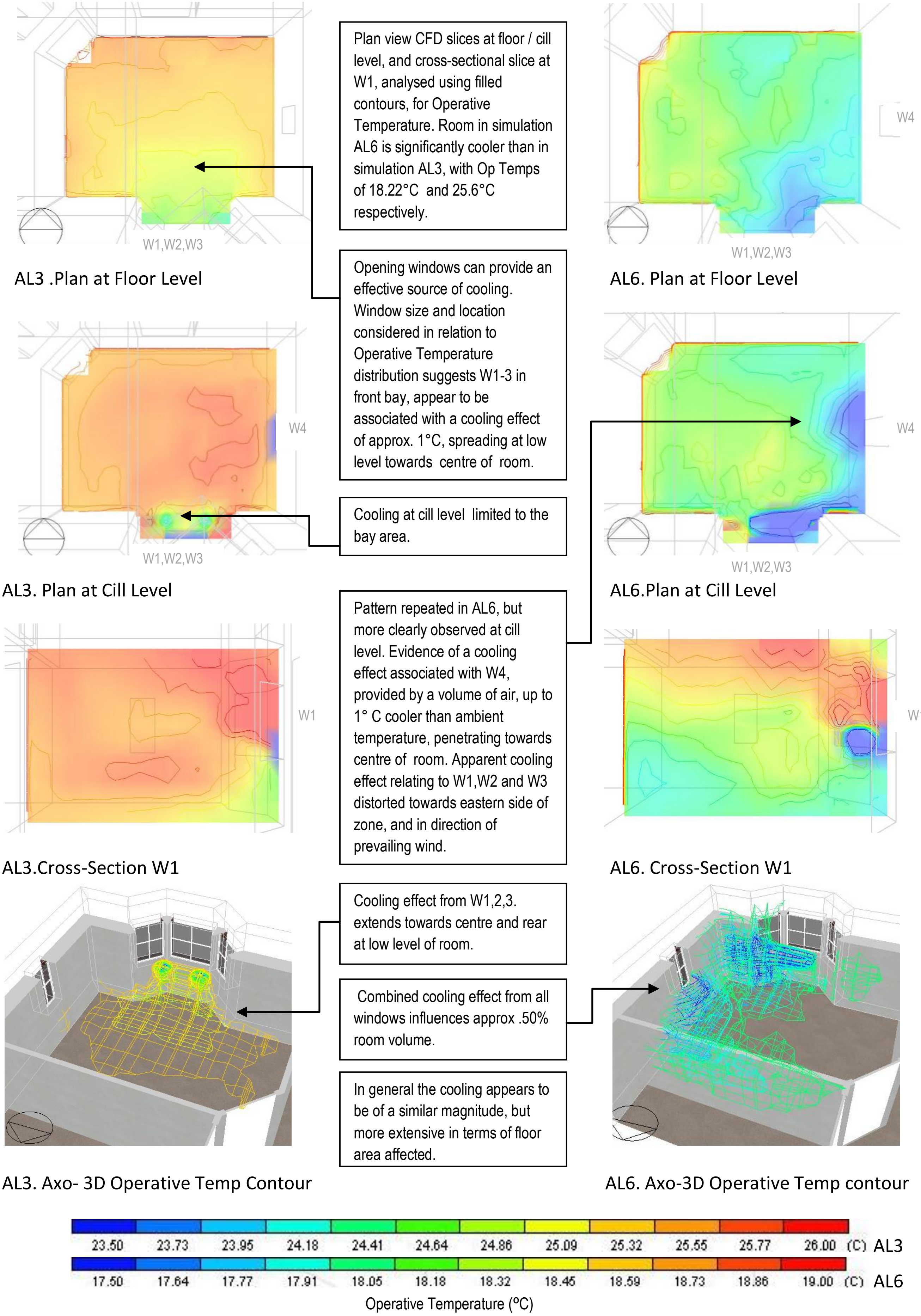

Figure 2. Comparative Analysis of Operative Temperature Distribution

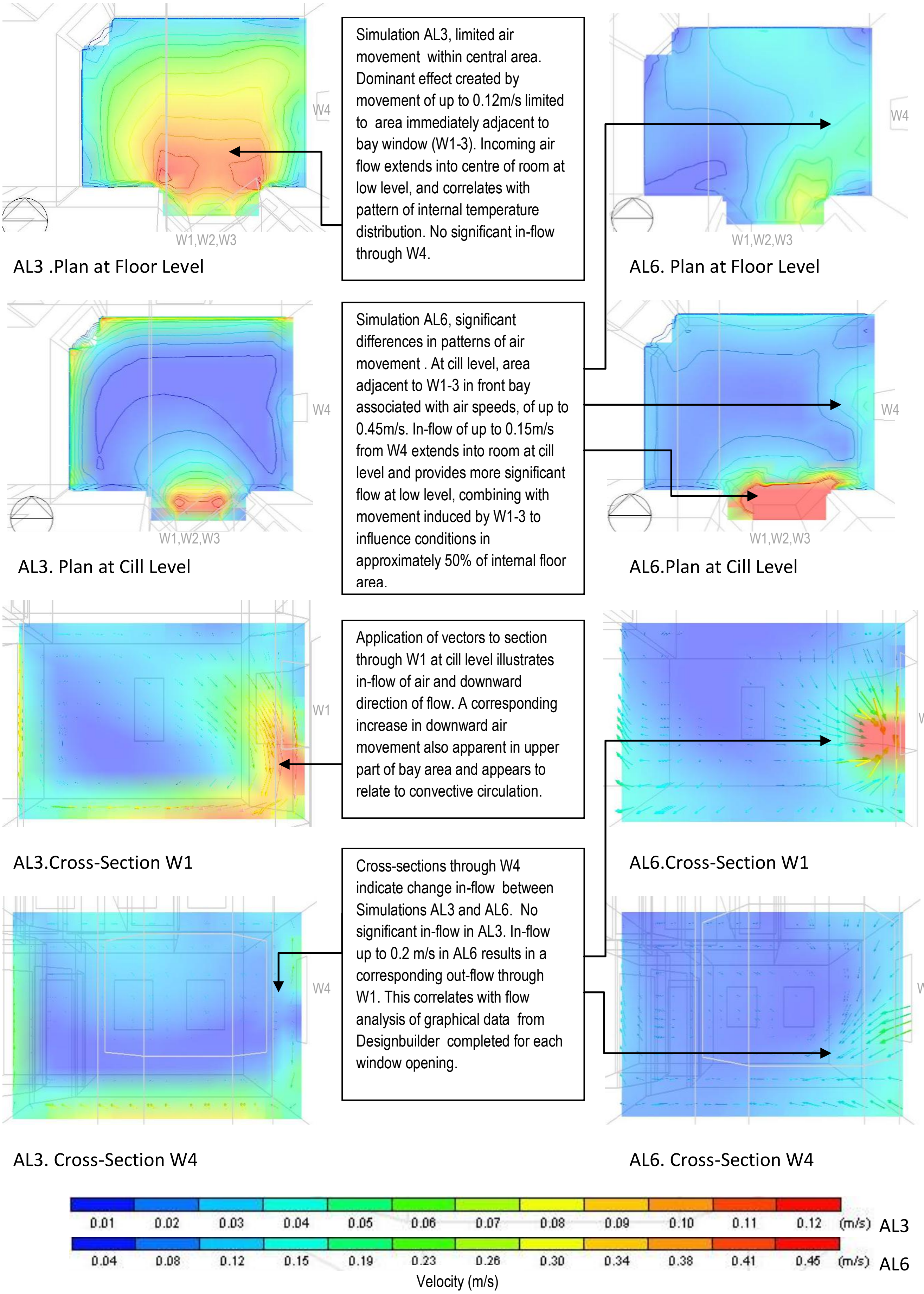

Figure 3. Comparative Analysis of Air Movement

Table 2: Comparison of Zone Temperature Distribution and Solar Gain for 15:00, 21st June

Variable	AL3 - Ground Cover Only	AL6 – Ground Cover With Trees	Reduction	Percentage Reduction (%)
Air Temperature °C	23.2	16.89	6.31	27.19
Operative Temperature °C	24.76	18.00	6.76	27.3
Outside Dry bulb Temperature °C	22.4	15.1	7.13	32.58
Solar Gain To External Windows kW	0.4516385	0.2046927	0.2469431	54.68

South-facing glazed openings in the building form suggest solar gain is likely to be a significant influence upon internal environmental conditions. Output data for solar gain to external windows is provided in Table 2 and illustrates that a reduction of 54.68% is achieved by the introduction of solar shading in the form of field maple trees. Analysis of axonometric images of the south-facing, front bay window showing 3-D contour mapping of mean radiant temperatures for each scenario also demonstrates the impact. At 15:00 hours the data for AL3 indicates significantly higher MRT values, at or above 26.5°C, compared to 19.5°C for scenario AL6. The beneficial effect of solar shading during the earlier part of the day is also illustrated by the relative distribution of values across the three windows. In simulation AL6, W1 (facing due south) and W3 (facing south-east) appear to be associated with lower MRT values.

3.2.2 Air Movement (Figure 3.)

The same series of plan views and sections were analysed for each scenario, using air velocity filled contours and vectors to interpret the speed and direction of air movement. It seems probable that increased levels of air movement and through ventilation evident in scenario AL6 are due to localised external air turbulence created by the interaction of prevailing winds and field maple trees.

4 CONCLUSIONS

Shading from the Field Maple trees appears to result in lower temperatures to both grassed and paved areas. This is more apparent in areas of concrete paving, where the thermal mass responds more quickly to insolation, and retains higher temperatures for longer. Tree shading appears to be most effective in reducing MRTs during the mid-morning and mid-afternoon, and could assist in alleviating the cumulative effect of heat gain throughout the day. The relative alignment and proximity of adjacent units could be significant in providing shadow and preventing higher temperatures between dwellings. Interaction of the building façade with cooling effects delivered by landscape elements suggests the supply of inflow air for natural ventilation and cooling, could be adversely influenced by hot spots. Specification of surface materials aiming to reduce this phenomenon could be advantageous within the near building zone, and wall construction adjacent to external ground level could also be significant in this respect. Vehicular access restricting hard surfaced areas to the shaded north side of the dwelling, could also be of benefit, and a consideration in terms of site layout.

The addition of the Field Maple trees reduces external air temperature by more than 30 percent and appears to have a positive impact upon internal comfort conditions. Shading reduces solar gain by more than 50 percent, and mid afternoon, mean operative temperatures are significantly reduced. Natural ventilation, limited by the size, and position of openable windows, is enhanced by the trees. Increased in-flow, contrary to wind direction, promotes through ventilation, and cooling influences a greater proportion of the living space. It seems probable this is due to localised external air turbulence created by the interaction of prevailing wind and field maple trees.

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