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Low Energy Case Study - Greenoak
by Alan Clarke

Introduction

Greenoak is a small independent housing association based in Surrey and Sussex. Previously the association took ownership of developer-built houses on mixed developments, but three new self-developed schemes gave the association the opportunity to address sustainability from scratch. In 2002, they commissioned the design of a 14 house development in Dartmouth Avenue, Woking. This was completed in March 2005. It was followed by 12 houses in Glaziers Lane, Normandy, Guildford, completed in July 2005. A third scheme of 12 houses in Storrington, W. Sussex was completed in 2009.

The aim was to develop a replicable model to reduce emissions, and other environmental impacts in mainstream housing, by incorporating cost effective and trouble free measures. Step-by-step improvements have been built into each development, based on experience from the previous scheme. The emphasis is on reducing energy demand by creating a well insulated and airtight envelope. The third scheme uses solar panels to meet half the hot water demand.

All houses are timber frame, designed to high standards of insulation and airtightness. The first development had mechanical extract ventilation. The second and third had mechanical ventilation with heat recovery (MVHR). Heating and hot water are provided by gas boilers, and the third scheme also has solar hot water collectors.

Energy data for the first two schemes have been collected over a twelve month period, around 2 years after completion. The third scheme is too new for any data to be available. The first schemes were built to the EcoHomes 'Excellent' standard, with SAP ratings (converted to SAP2005) of 82-83. The third is to Code for Sustainable Homes, level 4.

Actual energy consumption shows an average for the first scheme of 70kWh/(m^2.a) of gas for hot water and heating, and 42kWh/(m^2.a) electricity. This is equivalent to 185kWh/(m^2.a) primary energy and 40kgCO_2/(m^2.a), at SAP 2009 emissions factors.

The figures for the second scheme are 75kWh/(m^2.a) of gas for hot water and heating, and 47kWh/(m^2.a) electricity. This is equivalent to 204kWh/(m^2.a) primary energy and 44kgCO_2/(m^2.a), at SAP 2009 emissions factors. Planning requirements led to this scheme being built in the form of semi-detached houses, whereas the first scheme was built in the more efficient form of terraces. It should be noted that the occupancy levels of these houses are higher than SAP and PHPP assumptions (22m²/person), with a significant impact on energy use for hot water and electricity. Estimates, detailed below, put the proportion attributed to heating to be around 25kWh/(m².a), with average hot water energy consumption double that of heating.

Water use is on average 90 litres/person/day, without the use of rainwater or greywater recycling, neither of which were judged to be cost-effective, robust or significant in reducing environmental impacts.

Costs are as follows, all converted to current costs (4Q2009). Note reduction in costs on third scheme, due to simplified construction, despite higher thermal specification.

Figure 1. Building costs

	Dartmouth Avenue	***Glazier's Lane***	***Storrington***
Total building cost/m²	*£1,040*	*£1,258*	*£1,152*
Total external works/m²	*£255*	*£306*	*£376*
Total construction cost/m²	*£1,295*	*£1,564*	*£1,528*

Site details

32-52 (even) Dartmouth Avenue & 1-5 odd Dartmouth Path, Shearwater, Woking, GU21
Completed 2005
6 no. 2 bed, 4 person @ 80m²
1 no. 3 bed, 5 person @ 85m²
4 no. 3 bed, 5 person @ 86m²
3 no. 4 bed, 6 person disabled @ 108m²
(3 terraces of 3,4 and 7 units.)

1-12 Manor Farm Close, Glazier's Lane, Normandy, Guildford GU3
Completed 2005
4 no. 1 bed, 2 person @ 57m²
3 no. 2 bed, 3 person @ 65m²
3 no. 2 bed, 4 person @ 80m²
1 no. 3 bed, 4 person disabled @ 93m²
1 no. 3 bed, 6 person disabled @ 108m²
(6 pairs of semi detached units.)

1-12 Abbey Walk, Ravenscroft, Storrington, Pulborough RH20
Completed 2009
4 no. 4 bed, 6 person @ 93m²
1 no. 4 bed, 6 person disabled @ 101m²
3 no. 2 bed, 4 person @ 78m²
4 no. 3 bed, 5 person @ 80m²
(2 pairs of semi detached units and 2 terraces of 4 units each.)

Floor areas exclude mezzanine floors.

Fabric details

These are generally the same for the first two developments, although construction methods differed, with improved levels of insulation for the third development.

Foundation

The foundations used in the first two developments were mini-piles, without ground beams, to minimise the need to export brownfield soil and to minimise concrete use. The Storrington development uses steel screw piles, further reducing spoil removal and concrete use. The pile foundations mean that the houses can be built closer to existing trees than would otherwise be possible and avoids the cost and environmental implications of exporting contaminated soil.

The soil was removed to around 600mm depth (less where ground slopes), with the void edged with pre-cast concrete paving slabs bedded in concrete. A crushed, brick oversite layer was used.

Floor

The floor is suspended timber. For the first development this was using prefabricated panels; the other developments were stick-built on site. The construction uses LVL (laminated veneer lumber) beams to span the pile caps, with the floor made of 300mm composite timber I-beams at 600 centres, filled with cellulose insulation enclosed by bitumen fibreboard below and OSB above. A gas-proof membrane between OSB and ply flooring provides the airbarrier. The U-value = 0.12W/m²K. The Storrington development uses 350 I-beams at 400 centres with the flooring ply glued directly to the I-beam upper flanges (no radon barrier was required at this site). U-value = 0.10W/m²K.

Walls

The walls are timber frame, 140mm x 50mm studs, with 50 x 50 counter battens to the inside, fully filled with cellulose insulation behind a lining of oriented strand board (OSB) sheets. External finish is a 15mm bitumen fibreboard, breather membrane, 25mm battened cavity and lime render on stainless steel mesh. Some areas use natural finish timber cladding instead of render.

Internally, the OSB layer is sealed with a vapour control membrane, also forming the air barrier. After installation, a cross-battened 25mm service void is formed behind the plasterboard. The first development was built from large pre-fabricated panels, the later ones assembled on-site. U-value = 0.19W/m²K. The Storrington development uses a simplified construction of 140 x 38 studs, lined with vapour control membrane and filled with mineral wool. Then the internal 50 x 50 cross battens are added to form the service void combined, with 50mm mineral fibre insulation fill followed directly by the plasterboard. U-value = 0.15W/m²K.

First floor

Walls were assembled up to first floor, with the floor structure on top of the walls and the walls above built on the first floor (platform construction). The ends of the floor are wrapped with air barrier membrane, taped and lapped to the vapour control membrane in the walls.

The first development at Woking used I-beams for the first floor but changed to open-web composite beams for later developments to accommodate ventilation ductwork.

Windows

Triple glazed windows are used, with wooden frames seen internally but clad with aluminium externally to minimise maintenance. U-value=1.3W/m²K. Installation is in-line with the wall insulation, with a mastic seal between vapour control membrane and window frame at base and sides. Above a timber infil piece was sealed to both membrane and window with mastic. Storrington uses Passivhaus standard windows, U-value = 0.8 W/m²K.

Roof

The roof insulation is cellulose, between 300mm timber I-beam rafters, topped with bitumen impregnated fibre-board. Internally, plasterboard is fixed directly to the I-beams with a vapour control layer forming the air barrier. A service void is not required as all pipes, wires and ducts are run through the open web joists of the first floor construction and wall lights only are used on the upper floor. A warm mezzanine was formed over the upper floor, providing storage space to the bedrooms. U-value = 0.14 W/m²K. Storrington U-value = 0.10W/m²K

Air Barrier

The airtight layer is the internal face of the wall, floor and roof panels. This was sealed on assembly, and once the windows were installed, the shells were tested for air leakage. This put responsibility on the timber frame fabricator to achieve the specified standard before services installation started. The design target was 1m³/m².h but the contractor would only agree to 2.

Wiring and plumbing were surface fixed to the inside of the panels, and through an open truss first floor, so the air barrier was not penetrated except where necessary to get services in or out of the house. The detail used for this was to fill around pipes and ducts with mineral fibre insulation and expanding foam.

In the Storrington houses, the ground floor W.C. is located next to the kitchen to reduce the number of drain penetrations through the floor.

Pressure Tests

In the first and third developments one airtest was carried out per dwelling type. For the second development two dwellings were tested; once at completion of the envelope and once after services were installed. The first development had test results around 3-4m³/m².h@50Pa (2.96,3.38,4.40 & 3.97). The second had test results of 1.17 and 1.37 for the envelope and 2.73 and 2.31 after services installed. The third development had test results around 3m³/m².h 50 Pa (3.31,2.79,3.01,2.85,2.95 & 2.70).

Causes of Air Leakage

The first development, used large panels. Problems with the quality of construction of the panels, and site management, led to the air barrier membrane being damaged by water. The membrane was replaced in parts and sealing tape reapplied, but not with complete success. Problems were exacerbated by the termination of the timber frame subcontractor's agreement before completion because of poor performance.

For the second development the construction method was changed to on-site 'stick-built' assembly. The initial results for the completed shells were good, though the re-test figures show the importance of managing services' penetrations. Here, the timber frame contractor was responsible for airtightness of their work and took care, which is reflected in the first test result. Responsibility of the airtightness of services by contractors was down to the site agent and this was less successful.

For the third development, pre-fabrication was still considered as an option, but could not compete on price with on-site assembly. The same contractor was used for this as for the second development, but this time poor supervision by the contractor meant that the airtight membrane was not installed properly at the first floor junction and got damp, and the jointing tape didn't adhere properly, leading to airleakage.

Other leakage areas identified during air tests were poorly sealed doors and windows; incomplete sealing between window and door frames and the opening in the timber frame structure and incomplete seals around duct and pipe penetrations.

Continuity of Insulation and Thermal Bridging

The timber frame panels were designed with insulation zones abutting at corners and eaves. The large panels mean there is less doubling up of structure at panel joints than typical pre-fabricated timber frame designs. However, the frames still included more timber than necessary, owing to the rule-of-thumb structural design by the frame manufacturers. The Storrington development uses narrow studs, which reduce timber fraction (25% less timber per stud), though these are harder to hit with nails. A structural design was prepared for this development, but largely ignored by the timber framer who again added unnecessary timber.

The design includes cross battening of the 50mm battens which increase the insulation from the standard 140mm frame depth. The cross-wise orientation is to reduce the impact of thermal bridging, though in fact the first frame was delivered with the battens fixed/aligned to the main frame members so as to simply increase their depth to 190mm.

Ventilation System

The low air leakage of the houses necessitated mechanical ventilation to ensure good air quality. The first phase of building used mechanical extract ventilation only (by Aerco Ventilation Ltd). This was continuous extract from bathroom and kitchen, with humidity controlled wall inlets. The bathroom extract grilles include PIR detectors to boost extract when rooms are occupied, and there is a boost switch to increase air flow when cooking. The systems have been trouble-free, although have not always dealt with cooking smells well. Later developments have added recirculating cooker hoods, which help, although individual cooking habits prevent direct comparison.

The second phase introduced heat recovery, as an energy saving measure, using Vent Axia HRE 275 MVHR units. The mezzanine space above the first floor was used to make space within the insulated envelope for the heat recovery unit. This has not proved to be the best place, leading to noise breakout from the unit itself to the bedroom, since the unit was only separated by a cupboard door. Also, access for servicing and filter replacement is awkward.

The supplier did not commission the units well, leading to excessive airflow rates through individual terminals which added to noise problems. This has been corrected. Initially there were problems with wind-blown dust (from agricultural land) clogging the filters. This led to increased fan noise too.

The high noise levels experienced at first led to occupants turning the MVHR units off. This then led to condensation on windows – illustrating that the MVHR was working well to control humidity.

The third scheme uses Greenwood Fusion HRV1 MVHR located on the ground floor, easily accessible from the entrance to the house. This system is working satisfactorily so far; the additional experience gained by suppliers and installers eliminated most of the problems met with in the previous scheme.

Heating System

Conventional radiator heating is used, with a low NOx condensing gas boiler in each house. For the first two schemes combi boilers were used. The third uses Worcester Bosch system boilers. This is combined with solar thermal collectors, 2 no. Filsol FS20 flat plate panels, 4m^2 per house and a 250 litre thermal store.

Daylight/Lighting

The improved comfort from triple glazing meant that large windows could be installed for daylight. This has led to minimal use of electric lighting, and high levels of resident satisfaction. Initally, there were some problems of summer overheating, these were then resolved by retrofitting openers to the Velux rooflights, which were not accessible from floor level.The third scheme incorporates inward opening windows that can provide secure night time ventilation in combination with Velux rooflights. Low energy light bulbs and compact fluorescent lighting were used throughout.

Water Use

Efficient water use was designed in through the use of low water use WCs and showers, flow regulation, and a compact plumbing layout. No water recycling was used. External waterwas supplied by rainwater butts.

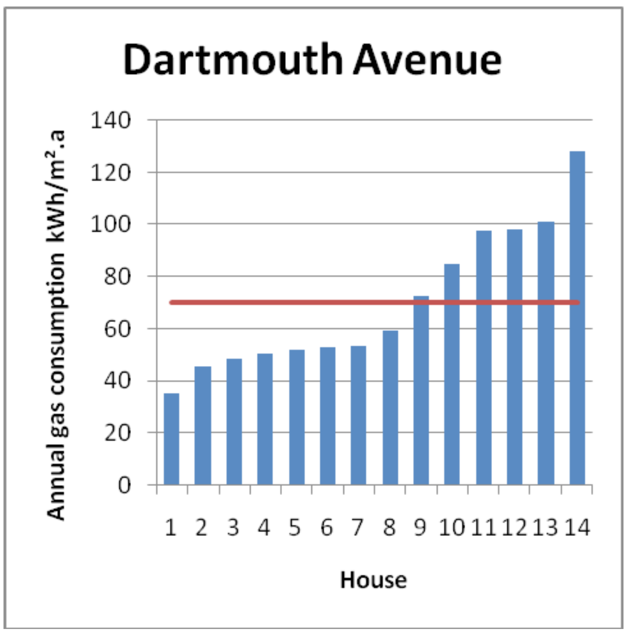
Energy data

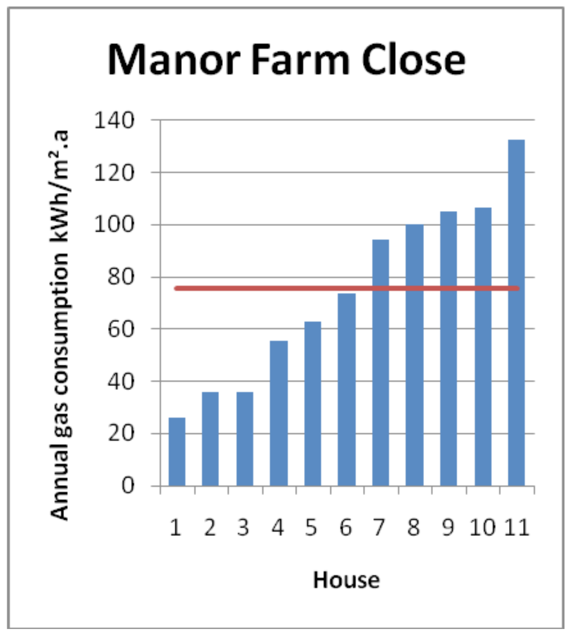
For both Dartmouth Avenue and Manor Farm Close, energy data was provided by the tenant's meter readings over the year 2007, combined with initial readings taken on tenancy start, at various dates during 2005. The meters read are total gas, electricity and water used. The monitoring was co-ordinated by Vicki March for Greenoak. Some later readings have been taken but the data was not available in time for this study. Readings were taken roughly every two months through 2007. The data seemed reasonably consistent, though for the final reading a number of households had switched to pre-payment meters and no readings were available. The annual consumptions derived over the period from start of occupancy until 2008 are very close to the 2007 figures.

As the houses are reported to need little heating, and use combi boilers, an estimate has been made of hot water energy consumption based on summer meter readings, which were seen to be very steady over the two monitoring periods covering July-September.

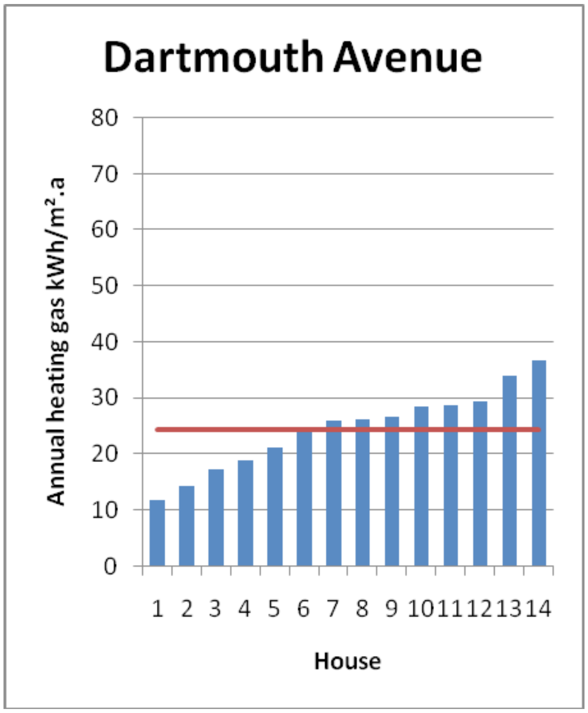
Gas use

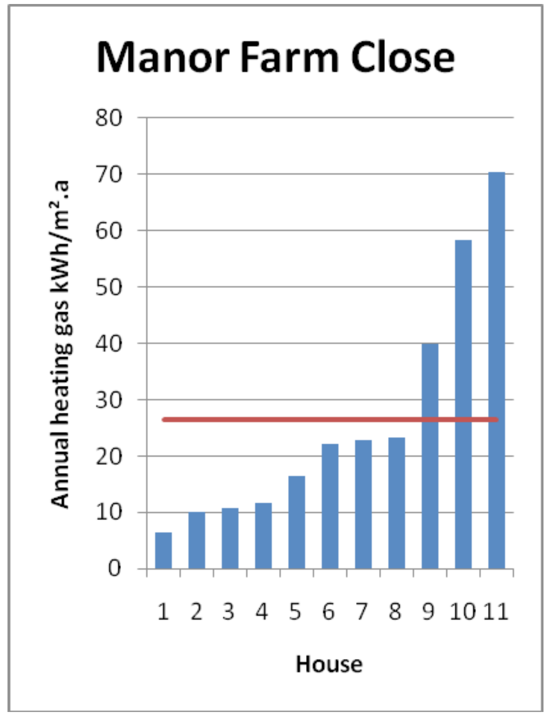
Average gas consumption was 70kWh/m².a at Dartmouth Avenue and 75kWh/m².a at Manor Farm Close. See graphs below.





The split into hot water and heating indicates that average heating gas consumption is 25 kWh/m².a whilst average hot water gas consumption is 45 kWh/m².a. Average occupancy is 20m²/person at Dartmouth Avenue and 27m²/person at Manor Farm Close, 22m²/person overall. This compares with assumptions of 31m²/person in SAP and 35 m²/person in PHPP. Heating-only estimates are set out in the following graphs.

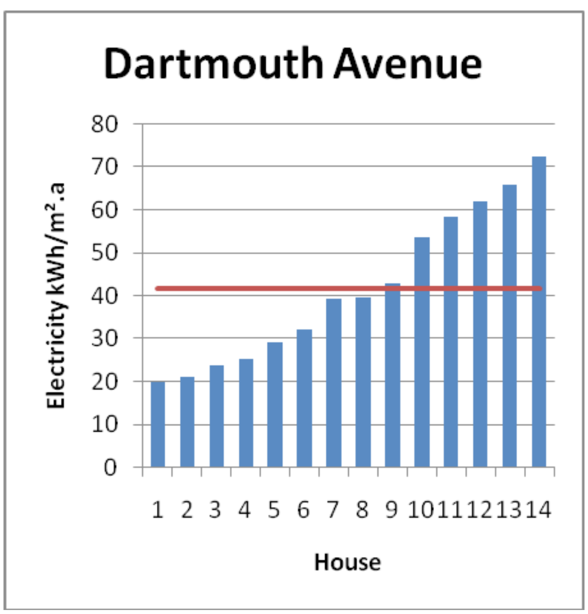


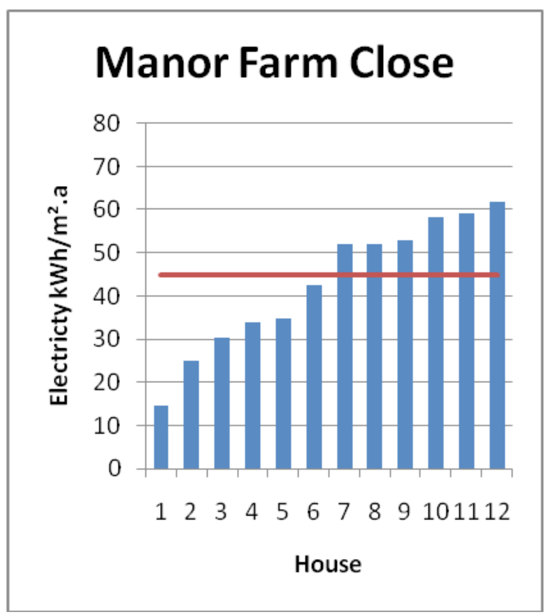


These results show the success in limiting building heat loss. The higher hot water energy consumption principally reflects the higher occupancy figures for these houses. These occupancy levels are typical for social housing, but unheard of in self-build "eco-houses". The high energy consumption for hot water despite best practice water efficient fittings informed the decision to install solar hot water on the third scheme.

Electricity Use

Average electricity consumption was 42kWh/m².a at Dartmouth Avenue and 45kWh/m².a at Manor Farm Close. See graphs below.





Again in square metre terms this looks high, but at 3600kWh/yr the average household consumption is 20% below the UK average. Comparisons were made between mechanical extract only ventilation, and heat recovery ventilation. Average heating energy consumption in the first two schemes appears almost identical, with gas consumption around 70kWh/m².a The range in both cases is between about 50% of the average to 180%. Airtightness in both schemes is around 3m³/m².h Only a sample of houses was tested. Without more detailed monitoring it is hard to make firm conclusions, but the energy consumption figures are consistent with the expectation that heat recovery ventilation offers little or no advantage over mechanical extract ventilation at this level of airtightness. Electrical consumption is 42kWh/m².a in the first scheme and 45kWh/m².a in the second, with variation from 30% to 170% on average. Again, the two schemes are remarkably similar, and no firm conclusions can be drawn at this level of monitoring.

User Feedback

Winter Comfort Levels

Resident satisfaction levels were surveyed by Vicki Marsh for Greenoak HA. Results for internal temperature in winter were 90% satisfactory or higher, and 95% were satisfied with draught-free nature of the houses.

Summer Comfort Levels

Residents reported overheating, and only 33% satisfied at first, rising to 63% once remote operation of rooflights was provided

Noise Levels

95% were satisfied with noise levels from outside and 88% were satisfied with noise levels indoors.

Health and Well Being

93% reported health improvements, 100% were satisfied with allergy improvements, and 100% were generally happy with their house.

Lessons Learnt

The lessons applied in the third project and other lessons for future developments were mainly involving air tightness. Insulation is easy, airtightness is hard. The use of composite timber beams in floor and roof have enabled very low U-values to be achieved without fundamentally rethinking how to build. The main difficulties experienced were in obtaining prefabricated panels to non-standard thicknesses, at competitive prices. For the walls there remains a problem in preventing timber frame suppliers from adding unnecessary timber, increasing thermal conductivity, as well as costs, to avoid more rigorous structural design. Counter battened insulated service voids and increased thicknesses of woodfibre external sheathing are effective means of mitigating the impact of this thermally, but work is needed on timber frame design to address the basic problem of high timber fractions.

Airtightness has been a struggle on all three projects in one way or another. The problems aren't physical, but rather are down to the system of subcontracting and of responsibility and supervision on site. When educated and motivated, builders have been able to deliver good results, but lack of responsibility or care from other contributors to the build can undo the good work.

This suggests that the best results will be obtained with different contractual structures, say with a low-energy building specialist overseeing the whole build and enforcing airtightness standards on the various trades. It is also indicates that what looks fine on the drawing also needs to stand up to the conditions on site, and be both testable and repairable if necessary. The identification of increased leakage owing to service penetrations shows these to be significant, and meriting specification of reliable and easily installable seals, plus training and monitoring of the work.

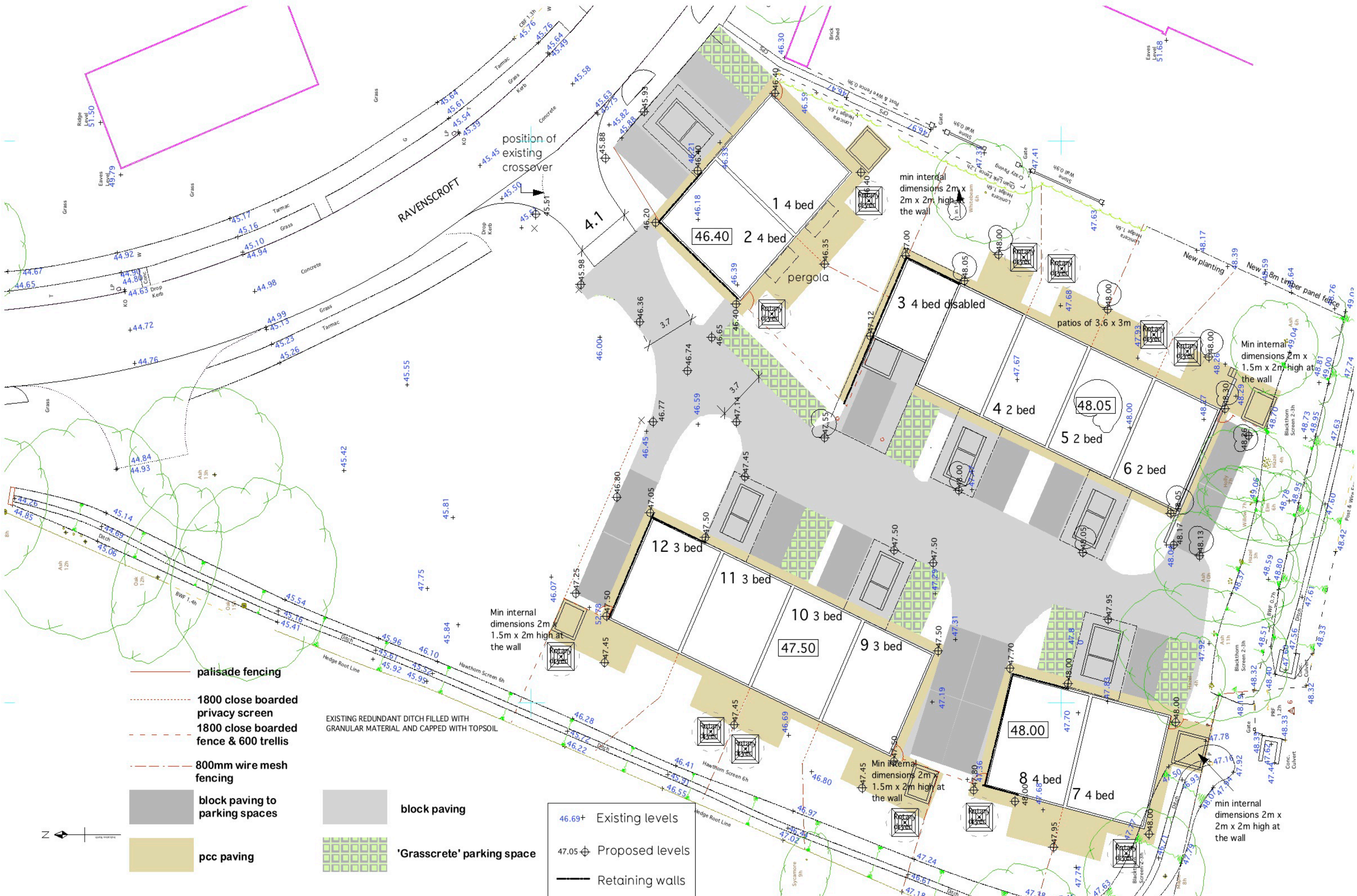
Mechanical Ventilation, a Learning Experience

When occupants turned their noisy new heat recovery ventilation systems off it was soon evident from the condensation that ventilation needs to be designed into an airtight house, and also that heat recovery ventilation works well at providing good air quality. What was learned on the design side was the importance of locating plant where it does not cause a noise nuisance and is easily accessible for servicing, and the importance of good commissioning of ventilation systems.

These lessons learnt, heat recovery ventilation is a practical, workable technology and residents have commented on the good air quality in the houses. In particular they report health improvements, one saying 'the air seems fresher in here, my kids had less hay fever'.

Acknowledgements

Thanks to Adrian Buffery of Greenoak Housing Association for providing energy monitoring data, and extensive client feedback on the performance of the houses in use. Thanks also to the architect of all three schemes, Jon Broome, for providing technical details, build costs, drawings, and photographs, as well as frank discussion of the practicalities of building to high standards of energy efficiency.



Revisions

J. New version of site layout
K. 02.05.08 Incorporation of dwgs 101 and 111. Parking to plot 4/5 amended
L. 16.09.08 Levels to plots 3-6 and immediete surround ammended.
M. 02.12.08 Block Paving in front of plot 3 extended to allow refuse access, rotary dryer positions added

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Client	Greenoak Housing Association
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Dwg No.	365.101
Revision	M
Scales	1:250
Date	12.06.07