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Evaluation of building performance in use – a case study of the Seager Distillery development



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Abstract

A two-year post-occupancy performance evaluation has been undertaken of the apartments within Galliard Homes' Seager Distillery redevelopment site in London. The Seager Distillery site is typical of the many new high-density developments in London, reflecting the tightening standards on energy use and pressure on land use. This paper presents the energy and environmental performance of three apartments studied in detail, including the assessment of the performance of the building fabric, MVHR units and the communal heating system.

The paper compares the actual performance against the design intent of the apartments and summarises the performance of the communal heating system in use. It then highlights the reasons for any performance gaps identified, which provide useful learning to both Galliard Homes and the wider building industry.

The study has demonstrated that measurements of the actual performance of the building fabric align with design expectations; however, issues were found in the performance of the MVHR systems in the apartments affecting thermal comfort and energy use. This was further exacerbated by the under-performing communal heating system, where various shortcomings have affected its design, installation and operation.

The study highlighted areas for improvement in the building and its services in terms of design, installation, commissioning and post-occupancy maintenance. Better building handover and occupant access to relevant information were identified to promote building usability and further contribute to closing the performance gaps.

Key Words:

Building performance, post-occupancy, communal heating, MVHR, air tightness

1. Introduction

There is increasing concern over the potential gap between the design intent of a building and its actual performance in terms of energy and summer comfort conditions. This gap is thought to arise from a variety of sources, ranging from the design of the building and the methods used, through to the buildability, procurement and construction process, which affect build quality, systems integration and commissioning, as well as the handover and operation of the building. This gap in performance could impact on the UK government achieving its aspiration for a low-carbon economy and its CO₂ reduction commitments. It presents a reputational risk to the house-building industry and it could damage consumer confidence in new-housing if energy bills are higher than expected and the buildings overheat.

In light of these concerns, the Technology Strategy Board (Innovate UK) committed up to £8 million to fund a four-year Building Performance Evaluation (BPE) programme on both domestic and non-domestic buildings, which commenced in 2010. The overall purpose of the programme was to evaluate the performance of buildings and support the building industry in delivering more energy efficient, better-performing buildings. This was to be delivered through detailed investigation of real buildings under use to derive substantive evidence of actual building performance and to help identify root causes, which need to be collectively addressed by the various sectors of the building industry, to close any identified gaps in delivered performance.

This paper presents the results of a two-year post-occupancy evaluation study undertaken under the TSB BPE programme. It has been carried out on apartments within Galliard Homes' Seager Distillery redevelopment site in London. This study aimed to develop an insight into a number of important features of recently-built housing, not sufficiently understood, of which (a) to (c) are covered in detail in this paper:

- a) The energy performance of the apartments;
- b) The efficiency of the communal heating scheme;
- c) Understand differences between as-designed and actual energy use by the apartments;
- d) Whether overheating occurs in the apartments;
- e) Occupant experience and satisfaction with the apartments.

2. The Seager Distillery site

2.1 Overview

The Seager Distillery site is a regeneration project by Galliard Homes on the site of a former distillery, which includes the refurbishment of a 19th century warehouse, a new crescent building, office pavilion and residential tower. It is typical of many developments that came forward in the 2000s in London, reflecting the tightening standards on energy use and pressure on land use,

which led to the building of high-density apartment blocks, rather than houses.

This site is distinctive in having a communal heating system to provide heating and hot water throughout the development. The main heat source is a gas Combined Heat and Power (CHP) plant supplemented by a biomass boiler and two conventional centralised gas boilers. The apartments are equipped with mechanical ventilation with heat recovery (MVHR) systems for the continuous provision of fresh air ventilation.

Specifically, the study focused on Norfolk House, which is one of the annex blocks completed within the first phase of the development. Norfolk House is considered representative of the site with similar build specification, design and procurement. There are a total of 58 apartments in Norfolk House, which feature full-height double glazing connecting the living rooms to the balconies. Various types of cladding have been used on the facade including aluminium insulated panels, aluminium rain-screen cladding, aluminium infill panels, aluminium spandrel panels, and timber cladding. Figure 1 shows the Seager Distillery development and Norfolk House.



Figure 1: The Seager Distillery site and Norfolk House.

The study particularly focussed on three apartments comprising the most common build-types within Norfolk House, which are detailed in Table 1. AECOM undertook an independent investigation of the buildings with support from Galliard Homes and Amicus Horizons (social housing provider, who part-owns the apartments). AECOM had no role in the development of the Seager Distillery site.

2.2 Communal heating system

Table 1 – Details of the apartment units monitored in detail				
Flat Number	Internal Floor Area	Number of Bedrooms	Aspect	Floor of Apartment Block
Flat 1	45m ²	1	west facing	4th floor
Flat 2	74m ²	2	west and east facing (dual aspect)	4th floor
Flat 3	63m ²	1	east facing	4th/5th floor (duplex flat)

A dedicated communal heating system provides heating and domestic hot water (DHW) throughout the development. Figure 2 illustrates the communal heating system layout taking heat from the energy centre to the different blocks throughout site, including Norfolk House. Separate building pipe network then distributes heat to the apartments via hydrostatic interface units (HIUs) for space heating and DHW provision.

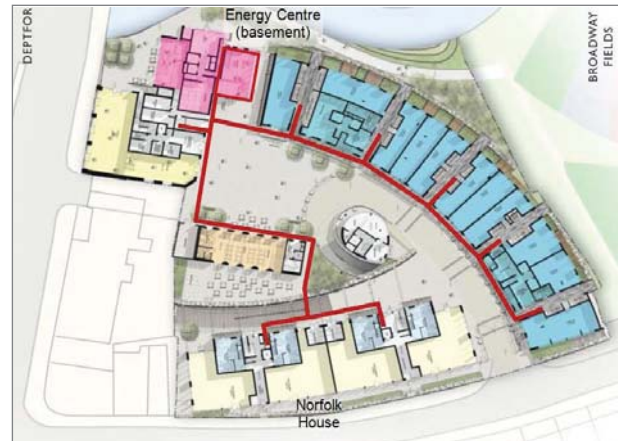


Figure 2: Communal heating supplying heat from the energy centre throughout the site.

Figure 3 shows the energy centre, which comprises the following:

- An 800kWh wood pellets fired lead biomass boiler to provide low carbon heat;
- An Ener-G 100 CHP plant with 165kWh and 100kWe;
- An 1000kW Hoval Cosmo gas boiler installed in Phase 1 and 1500kW Hoval Cosmo gas boiler in Phase 2;
- An 18,000 litre thermal store to buffer CHP and biomass boiler output.

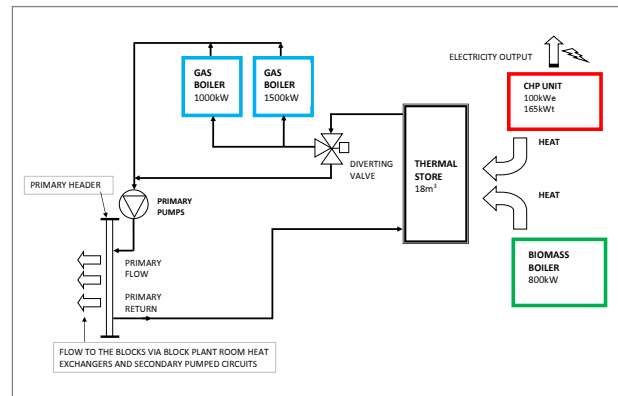


Figure 3: Block diagram of the communal heating system.

3. Methodology

The study was carried out over a two-year period and comprised both quantitative and qualitative evaluation of the performance of the apartments and the communal heating system. Figure 4 illustrates the setup for real-time measurement on site. The following measurements were recorded at 5-minute intervals with the data remotely accessed on a weekly basis by AECOM:

- Total electricity, heat (space heating and DHW) and water consumption;
- Separate electricity sub-metering of the MVHR system, lighting, power sockets, heating system and cooking hob;
- Temperature, relative humidity and CO₂ levels within the apartments as well as the local weather condition at the site.

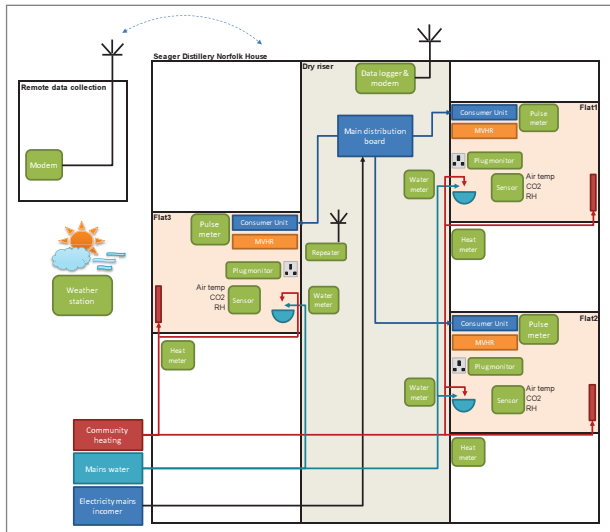


Figure 4: Diagrammatic illustration of the real-time measurement setup in Norfolk House.

In addition, plug-in energy meters were used to monitor energy use of selected individual appliances to provide further granularity in the electricity consumption data.

Actual energy consumptions measured for each of the three apartments were compared against their corresponding SAP figures. SAP or Standard Assessment Procedure is the UK Government's recommended method system for measuring the energy rating of residential dwellings, which is used specifically for building regulation compliance purposes. Comparison using SAP figures has been carried out in the study to benchmark against actual consumption.

In order to assess the build quality of the development, the air leakage and fabric thermal conductive performance of Norfolk House were measured by a specialist contractor:

- Air tightness tests were carried out in each of the three apartments, initially during the summer of 2013 and then repeated a year later. This testing was undertaken using a "blower-door" test in accordance with the procedures described in the ATTMA technical standard, TSL1 October 2010;
- In-situ U-value tests were carried out to determine the thermal performance of external walls of the apartments using heat flux sensors mounted on internal surfaces, which measured heat flow directly through each wall to correlate with corresponding internal and external air temperatures. Further inspection of the fabric thermal performance was carried out using thermographic imaging survey on both the interior and exterior of the apartments.

The performance of the MVHR system was also investigated:

- Measurement of flow rates were compared against commissioned figures and values from Approved Document Part F of the Building Regulations. In addition, continuous measurement of MVHR energy use was combined with flow measurements to determine the fan efficiency of the units;
- Visual inspections were carried out where possible to determine both the quality of installation as well as the

condition of the filters, which provided a general indication of the level of maintenance of the units.

A specialist contractor measured the MVHR air flow rates in each apartment in accordance with the BSRIA Guide BG46/2013, *Domestic Ventilation Systems – A Guide to Measuring Air Flow Rates*. An air capture instrument was used to measure the air volume from the supply and extract terminals in the apartments, by fully enclosing the terminals with the inlet hood of the instrument. This instrument has a built-in fan and pressure compensation facility, with an accuracy of $\pm 3\%$ of reading $\pm 1\text{m}^3/\text{h}$.

A series of walk-through audits and visual inspections of building services and the construction details in the apartments were also carried out to identify any issues which might lead to shortcomings in building performance. This was supplemented by feedback obtained through informal occupant and developer interviews and through questionnaires employing the Building User Survey (BUS) methodology⁽¹⁾.

4. Key findings

4.1 Fabric performance

The air tightness results are summarised in Table 2, together with the as-designed SAP values as well as the on-completion air tightness testing for the same apartment types (not the actual apartments monitored here) obtained from test certificates issued during construction.

Table 2 – The air pressure test results

Air pressure measure	Air permeability at 50Pa ($\text{m}^3/\text{h}\cdot\text{m}^2$)		
	Flat 1	Flat 2	Flat 3
Design air permeability (SAP)		8.0	
On completion (original testing contractor)	4.5	4.2	5.6
Initial air pressure test results in the study	2.4	3.2	3.6
Repeat air pressure test results in the study	2.8	2.6	3.6

The initial and repeat air tightness tests undertaken as part of this study were significantly lower than assumed in the design stage SAP assessment and 1 to 2 $\text{m}^3/(\text{h}\cdot\text{m}^2)$ better than those tested for similar apartments on-completion. Potential causes of the difference between the on-completion and current study testing include the following:

- Variations between the actual apartments tested for the corresponding given apartment type;
- Changes to the building fabric air tightness over time. This may be due to the building drying-out and settling down. Furthermore, leakage paths through small gaps in the building fabric may get clogged up;
- Significant differences may have resulted from different organisations undertaking the two sets of air tightness tests

and arisen due to variations in the methodology employed and the calibration of the equipment used. However, there was insufficient data collected to account for the magnitude of discrepancy in the measurements.

Reviewing the literature, it is noted that another study of three rounds of air tightness measurements in 10 low-energy new homes during the first 18 months of occupation also showed a general improvement of the air tightness across the period⁽²⁾. A further study suggests that the type of dwelling, construction, heating and ventilation all have a bearing on the extent to which air permeability changes over time⁽³⁾.

While the air tightness results were relatively low, smoke tests have identified leakage paths under sinks, wall power sockets and light fittings, which present potential areas for future improvement.

Limited in-situ U-value tests⁽⁴⁾ were carried out by a specialist contractor on the general external facing wall of the apartments. However, there were problems with the testing leading to data only for one apartment and one section of wall. The results suggest that the actual performance is close to the design value (actual value of 0.23 W/m²K compared to a design value of 0.25 W/m²K), although more extensive measurements would be required to verify this finding.

Thermographic imaging⁽⁵⁾ was undertaken by a specialist contractor both internal and external to the apartments. This includes measurement of the Thermal Index as a metric for fabric performance. The Thermal Index is the ratio of (surface temperature – external temperature) and (internal ambient temperature – external temperature). The contractor provided a correlation between the Thermal Index and U-value as shown in Table 3.

Table 3 – Equivalence of Thermal Index and U-values							
Thermal index	0.50	0.75	0.80	0.85	0.90	0.95	0.97
U-value	3.8	1.9	1.5	1.2	0.9	0.35	0.25

The reported Thermal Index generally suggested actual U-values are in-line with design expectations. Some cold spots were identified, which highlighted potential areas for future improvement. Examples include: (i) colder areas at the top of “boxed-in” sections, perhaps covering section of pipe work, with air leakage problems, (ii) cold bridging from large dabs behind the plaster board, and (iii) some evidence of cold bridging due to penetration of stud-wall fixings. Figure 5 shows images of the latter two examples.

No specific anomalies were identified on the external façade from the surveys carried out. It should be noted that glazed sections provide some ambiguity when interpreting fabric performance, which is prevalent for Norfolk House. In addition, a high proportion of its opaque fabric consists of ventilated rain-screen cladding, which further renders the external survey ineffective.

However, salient features remain evident from the survey in the form of higher recorded temperatures related to MVHR outlet vents above windows and thermal bridging around some openable

windows as shown in Figure 6. Also shown are the thermography images of the underside of some of the apartment balcony floor slabs. It can be seen that the surface temperature is higher at the interface with the external wall, indicating potential thermal bridging caused by the penetration of steel structure.

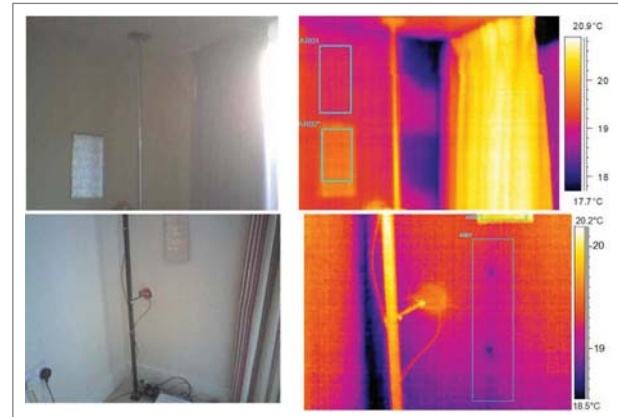


Figure 5: Thermography images showing (top) cold bridging (dark-blue patches) from dabs on plasterboard and (bottom) from penetration of stud-wall fixings.

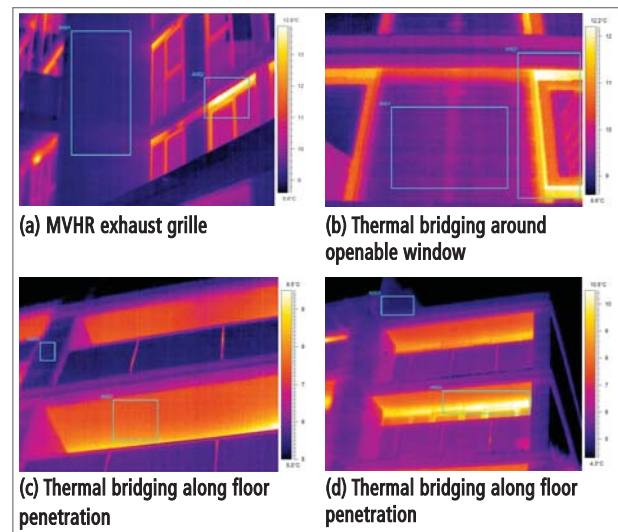


Figure 6: Thermography image showing heat loss (a) on the external façade of Norfolk House associated with the inlet/exhaust vents of the MVHR system, (b) thermal bridging around an openable window and (c & d) thermal bridging on the underside of the apartment balcony floor slab of Norfolk House potentially due to structural steel penetration at the façade..

4.2 Ventilation: MVHR system

The MVHR system is used to provide fresh air supply into the living room and the bedrooms, tempered via heat recovered from return air extracted from the kitchen and bathroom. The MVHR unit is capable of a normal and boost operation with a manufacturer-specified heat recovery effective up to 95% (not tested in the study). Both the supply and extract air are filtered at the MVHR unit.

Visual inspection of the MVHR system in the apartments highlighted several issues which might potentially affect the overall performance in the provision of ventilation and energy use. On first

impression, it would appear that considerable amount of flexible ducts could have been used at the MVHR unit connections as well as near the extract and diffuser terminations. However, due to limited access it has not been possible to fully ascertain this. There were also some diffuser caps which appear to have been adjusted and these affect flow rate as the locks have not been properly fastened.

In general, the location where the MVHR units were installed made access difficult, being part-constricted by soffit in the airing cupboard, which would require removing to access the MVHR units. A visual inspection of the interior of one of the MVHR units revealed the following, for which photos in Figure 7 illustrate the findings:

- The filters were dirty, particularly the extract air filters. This is likely due to the units being installed and commissioned during on-going construction work and, thus, capturing dust. The occupants appeared unclear as to what maintenance was necessary and who was responsible. Indeed, this is representative of a wider concern from residents that they had not received instruction on the use of their ventilation and heating systems. Impeded access could have further contributed to lack of filter cleaning/change;
- The external supply grilles were found to be covered with dust. The location of some of the external grilles does not allow easy access for cleaning.



Figure 7: Dirty extract filter (half cleaned for comparison) and clogged up external inlet grille.

The measurements of the MVHR ventilation rates for the apartments recorded by the specialist contractor are presented in Table 4 to Table 6. Measurements were also taken after the extract filter of the MVHR unit in Flat 1 was cleaned in order to assess the difference in performance. Upon cleaning, the airflow rates approached those from the commissioning data as shown in Table 4. This observation may also apply to the other two apartments which, if the filters were cleaned, may result in the commissioning test figures being achieved.

In general, the air flow rates measured on the supply and extract terminal in Flats 1, 2 and 3 are all below the values reported in the commissioning certificates. Furthermore, at normal mode operation, the flow rates did not appear to achieve the recommended ventilation rates in Part F 2006 of the Building Regulations for Flats 2 and 3.

Under-ventilation in dwellings can lead to problems of poor indoor air quality and health. For example, excessive moisture build-up from cooking, bathing and other processes can lead to condensation and mould growth. Occupant exposure to resultant moisture-related allergens can increase the risk of respiratory

Table 4 – The MVHR air flow test carried out for Flat 1

Flat 1	Measured in study (l/s)				Commissioning data (l/s)	
	"As-found"		"Clean"		Normal	Boost
Location	Normal	Boost	Normal	Boost	Normal	Boost
Living room	7.2	10.3	7.8	10.5	7	No data
Bedroom	5.5	7.5	5.5	7.7	6	No data
TOTAL SUPPLY	12.7	17.8	13.3	18.2	13	No data
Bathroom	-7.7	-9.8	-8.9	-13	-7	-13
Kitchen	-2.8	-4.8	-4.5	-6.0	-6	-8
TOTAL EXTRACT	-10.5	-14.6	-13.4	-19	-13	-21

Table 5 – The MVHR air flow test carried out for Flat 2

Flat 2	Measured in study (l/s)		Commissioning data (l/s)	
	Normal	Boost	Normal	Boost
Living room	1.9	2	7	No data
Master bedroom	2.4	3.8	6	No data
Bedroom	3.3	4.4	-	No data
TOTAL SUPPLY	17.6	10.2	13	No data
Bathroom	-3.6	-4.6	-7	-13
Kitchen	-5.2	-6.4	-6	-8
TOTAL EXTRACT	-8.8	-11	-13	-21

Table 6 – The MVHR air flow test carried out for Flat 3

Flat 3	BSRIA measured (l/s)		Commissioning data (l/s)	
	Normal	Boost	Normal	Boost
Living room	4.6	10	7	No data
Bedroom	4.9	10.9	6	No data
TOTAL SUPPLY	9.5	20.9	13	No data
Bathroom	-3.7	-7.6	-6	-8
Toilet	-3.2	-9.9	-4	-6
Kitchen	-3.7	-6.8	-7	-13
TOTAL EXTRACT	-10.6	-24.3	-17	-27

Table 7 – MVHR measured SFPs under normal and boost operations

Flat	State	Normal (W/l/s)	Boost (W/l/s)
	Flat 1	"As-found"	1.34
"Clean"		1.27	1.95
Flat 2	"As-found"	1.31	2.32
Flat 3	"As-found"	1.51	2.03

symptoms and asthma⁽⁶⁾. It should be noted that no health-related issues were reported in this study.

The MVHR Specific Fan Power (SFP) for each apartment is tabulated in Table 7, determined by taking the metered fan power consumption (W) and dividing this by the measured flow rate (l/s) (maximum between the supply and extract rate) for the different

As a result of the low system efficiency and the use of gas boilers only, it has been calculated that the CO₂ emissions are significantly higher than predicted by SAP. These range from 74% to 182% greater than predicted by SAP, depending on the apartment unit. It can be expected that the CO₂ emissions will improve somewhat as: (i) an increased number of buildings come on-line (i.e. increasing the heat load and improving distribution efficiency), and (ii) the CHP is used.

Galliard Homes have also identified several fundamental design, installation and commissioning issues impacting on the system performance.

- Investigations have revealed additional and unnecessary gas solenoid valve and under-sized gas pipework, which resulted in low pressure to the boilers causing the second gas boiler being unable to run. The gas pipe sizes did not appear on the schematic drawings, which was not flagged up or picked up by the contractor or installer. Galliard Homes now audit all projects to ensure that detailed gas schematics are produced;
- There were also issues with inappropriate heating pipework design and commissioning of control valves that consequently led to intermittent disruptions of DHW supply, which took considerable effort for Galliard Homes to identify the cause. In relation to this, Galliard Homes also found unnecessarily large number of heat exchangers being specified. Improved design and tighter control of commissioning would help alleviate issues leading to supply disruption in future;
- There have even been issues with the conventional gas boilers – incorrect wiring of the BMS modulation signal to the gas burner led to Boiler 2 modulations not being controlled correctly which can potentially damage the unit. This was further exacerbated by problems with the air damper control mechanism on one boiler burner, which has caused heat outages resulting in, at times, residents left with no heating for periods of up to 24 hours. Remedial works to the boiler burners have since prevented further outage of the entire system.

4.4 Overheating

The 2006 CIBSE Guide A⁽⁹⁾ recommends that for living areas, less than 1% of occupied hours should be over an operative temperature of 28°C and for bedrooms, less than 1% of occupied hours should be over 26°C. We have assumed that ambient temperature equals to operative temperature (i.e. air temperature equals radiant temperature).

Furthermore, as the apartments could potentially be occupied for much of the time depending on the activities of the occupants, we have assumed that the bedrooms are occupied from 10pm to 8am, and the living rooms are occupied from 8am to 10pm.

In summary, all three apartments experienced periods of overheating during the summer of 2013 in both the living rooms and bedrooms monitored. In particular, during July 2013, all bedrooms and living rooms overheated for a period between 27% and 58% of occupied hours.

This overheating could be due to a combination of (i) the high amount of glazing rendering the apartments susceptible to excessive solar gain, (ii) the MVHR in some of the apartments operating with a ventilation rate below that recommended by Part F of the Building Regulations, which also appear not to feature the capability for summer by-pass, and (iii) the three apartments were all on upper levels of the building such that there was no shading from balconies of the level above, which lower level apartments benefit from.

In addition, another contributor is the likely distribution heat losses within the apartment building from the communal heating system during the summer period. The issue of overheating in the neighbouring 26-storey residential tower building on the site was sufficiently pronounced such that it became necessary to retrofit automatic opening vents in the smoke shaft to purge heat in the summer from the core and communal corridors.

The Building User Survey (BUS) carried out has highlighted that occupants perceived that internal temperatures in summer were too hot and that they have insufficient control of cooling. In addition, BUS feedback on relatively high external noise levels (it is noted that construction was continuing on the site, which will have contributed to external noise) may have resulted in an unwillingness to open windows to reduce the temperature.

NHBC Foundation⁽¹⁰⁾ has highlighted concerns of overheating from recently constructed homes and identified design issues that should be addressed. The report similarly recognises potential problems arising from heat gains from communal heating systems, the need for adequate ventilation and impact of excessive solar gains, all of which are consistent with the observations made in this study.

4.5 Energy use and benchmarking against SAP

Measured heat (combined space heating and hot water) and electricity consumption within the apartments collected between March 2013 and June 2014 were compared to that predicted by SAP. For space heating, the heating degree day method using corresponding local measured weather data was used to modify the SAP predictions to better represent the influence of actual weather conditions and approximate the monthly variation in the proportion of space heating.

Figure 8 compares the predicted and measured actual heat consumption in the three apartments. The measured consumption is the lowest for Flat 1 among the three apartment units as it has both the smallest floor area and only one external façade, whereas the other two apartments have a larger floor area and larger external wall area with dual-aspect external façade for Flat 2. Flat 3 is a duplex unit over two storeys.

SAP over-predicted the heat consumption. The actual heat load would tend to be reduced by both better actual air tightness and observed ventilation rates being less than assumed by the SAP assessment. Furthermore, the apartments are thought to benefit from (unmeasured) heat gains arising from the distribution heat losses from the communal heating system (see Section 4.3).

Figure 9 shows the energy use for fans and pumps in the



Figure 8: SAP and actual heating energy use for the three apartments for March 2013 to the end of June 2014.



Figure 9: SAP and actual fans and pumps energy use for the three apartments for March 2013 to the end of June 2014.

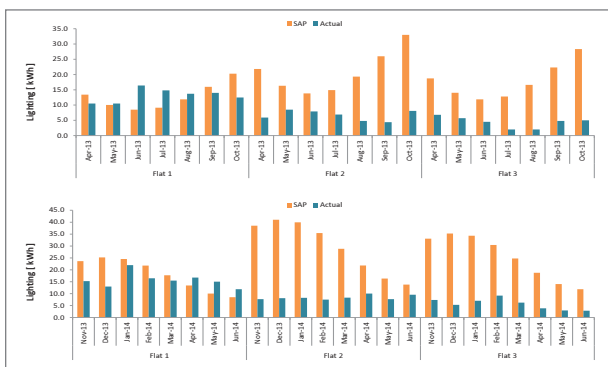


Figure 10: SAP and actual lighting energy use for the three apartments for March 2013 to the end of June 2014.

apartments. In this case, the actual consumption tends to be higher than predicted by SAP. This was partly due to occupant behaviour with Flat 1 continuously using the MVHR on boost setting until the start of 2014 when the occupant was made aware by the investigating team of how to use the ventilation controls. Another key reason is the efficiency of the MVHR units being less than half of that given by the product test data used in SAP. However, this was tempered somewhat by the ventilation rates in Flat 2 and Flat 3 being lower than recommended by Part F.

Figure 10 shows the lighting consumption for the apartments. The

results from Flat 1 were similar to SAP prediction. However, both Flat 2 and Flat 3 used significantly less lighting than predicted. This may be explained by the feedback from the occupants of these two apartments who preferred stand-alone lighting, which used power from the wall sockets.

The electricity use for stand-alone lighting was not separately measured to reconcile this lower-than-predicted consumption of fixed lighting. This reduced the need, and thus energy consumption, for ceiling lights which were on the lighting circuit. There is no evidence in this study to suggest that the reduced energy use for artificial lighting was linked to provision of good daylight in the apartments, which was not investigated in the study. Finally, it is also noted that 100% low energy lighting was installed in the apartments, which is greater than that assumed in SAP and would tend to further reduce the actual energy use.

Table 9 provides an overall summary of the annual SAP predicted and actual energy consumption (space heating, hot water and electricity for fan, pumps and lighting) for the three apartments. It also shows the total measured energy use including that measured for power sockets for comparison between each apartment units.

Table 9 – Comparison of annual regulated energy consumption between measured and SAP predictions for the three apartments					
Apartment Unit	Space heating and hot water		Electricity – fan, pump, lighting		Total actual including power sockets use
	SAP	Actual	SAP	Actual	
	kWh/m ² /yr	kWh/m ² /yr	kWh/m ² /yr	kWh/m ² /yr	kWh/m ² /yr
Flat 1	66.84	22.97	5.86	9.77	67.23
Flat 2	75.16	46.22	5.86	2.73	68.83
Flat 3	78.76	29.21	6.54	3.72	54.03

5. Lessons learned

Galliard Homes have identified a series of lessons learned from this study, several of which are highlighted below:

- Appraisal of the communal heating scheme design at the Seager development has led to recommendation for different design approaches to be adopted for 100 to 300, and 1000 or more apartment development sizes, which is vital for the design, to adequately account for phased completion. For example, smaller schemes below 300 units can have primary heating water delivered from the plant room directly to the radiator circuits in the apartments without any heat exchanger break. Also, phasing would require separate pumped circuits to each block to facilitate phased commissioning of the heating system. This would allow heat meters to be fitted to each circuit so that residents who have moved in could be charged accordingly and fairly;
- Plant oversizing was found to result from the lack of appropriate adjustments to accommodate changes in the

demand, as the site design evolved. This then led to issues with plant operability in practice. This is further exacerbated during the planning stage whereby plant sizing was derived based on a methodology to achieve CO₂ reduction to meet planning targets, which does not appropriately account for diversity in DHW demand. Also, it is vital that compliance calculations are not used for plant sizing and design calculations. References to the Danish DS439 standards for more appropriate account of diversity in DHW demand would further inform appropriate plant sizing;

- Current pipework insulation standards may be insufficient to limit heat loss, prevent corridors and apartments from overheating and to prevent heat gains in the mains water. Galliard Homes are now moving towards adopting the ECA – NES Y50 Enhanced insulation standard⁽¹¹⁾⁽¹²⁾;
- Appropriate levels of heat metering should be installed to enable measurement of system operation and performance. This will enable better management of heat billing during phased completion;
- Issues were identified with regard to the installation and commissioning of the energy plant, particularly with the system controls, which have impacted on its operation. Key learning points are the need for more detailed design specifications for installation and commissioning and the procurement of an experienced mechanical and electrical installation company, capable of delivering to expected standards;
- Detailed BMS control philosophy is essential to ensure accurate description of system operation and facilitate precise implementation by installers;
- A more prescriptive and robust commissioning requirement would help ensure the various issues encountered with the communal heating system, as well as the MVHR units in the apartments, could be significantly minimised;
- Feedback from the occupants was that whilst a large amount of useful information was provided in the form of documentation, it did not provide all of the practical information. In particular, it was recommended that face-to-face orientation/handover would have been helpful. This should include the correct operation and maintenance of the MVHR system. Points raised in this study included the inappropriate use of the boost switch and clogged up extract filters and external inlet grilles.

exacerbated the risk of overheating in the apartment and thermal comfort in the summer.

The electricity use for fixed building services within the three apartments is more variable in comparison with SAP, reflecting the diverse nature of occupant behaviour and hence the use of the building. For example, the occupant preference for stand-alone lighting in two apartments resulted in lower measured fixed lighting energy than predicted for these apartments but with increased demand from power sockets where stand-alone lighting was used.

While a large amount of information was provided in the form of documentation, the occupants identified that it did not provide all of the practical information. Face-to-face orientation would have been helpful. For example, the electricity consumption highlighted that one occupant was unaware of continually using the MVHR system on boost setting and discussion with the occupants suggested lack of clarity on responsibility for maintenance.

The communal heating system has not performed to expectation with low overall system efficiency, largely thought due to high distribution losses in the heating pipe network. Distribution losses in the communal heating pipe could be the result of the quality of pipework installation and/or the standards of insulation on heating pipework being below that necessary to achieve reasonable losses. Faults due to the generally poor quality of design, installation and commissioning have also contributed to heat outages, poor performance and under-utilisation of the low carbon technologies (biomass boiler and CHP engine) intended to reduce CO₂ emissions.

The study has highlighted some clear issues, which have resulted in performance gaps between the design and actual building performance. The causes identified cover the entire process, from the design stage, through to the quality of the construction process, and finally to the commissioning of the building services and handover to the building occupants such that they understand how, and are motivated to, operate the building in a correct and energy-efficient manner. Indeed, the highly-diverse occupant behaviour in a domestic setting results in an inherent tendency for significant differences between actual and predicted performance. This should also be recognised when highlighting the performance gap.

6 Summary

Overall, the heat consumed by the three apartments is significantly less than that predicted in SAP. Contributing factors are found to be high fabric thermal performance, low ventilation rates and uncontrolled gains from solar and heating pipe distribution losses. While fabric thermal performance reflected well-executed design intent, low ventilation rates were a result of the under-performing MVHR system, which also led to relatively higher associated energy use. Sources of heat gains, which may be desirable in winter,

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Glossary

MVHR	Mechanical Ventilation with Heat Recovery
SAP	Standard Assessment Procedure is the UK Government's recommended method system for measuring the energy rating of residential dwellings.
ECA	Enhance Capital Allowance is a scheme whereby a business can invest in energy-saving plant or machinery that might otherwise be too expensive. The first year allowances let businesses set 100% of the cost of the assets against taxable profits in a single tax year.
NES Y50	Standard of enhanced pipework insulation specification
CfSH	Code for Sustainable Homes is an environmental assessment method for rating and certifying the performance of new homes in England, Wales and Northern Ireland.
SFP	Specific Fan Power
BMS	Building Management System
DHW	Domestic Hot Water
BUS	Building User Survey or BUS is a licensed methodology created from thirty years of continuous development in building use studies for post occupancy evaluation.
NHBC	National House Building Council
CHP	Combined Heat and Power
BPE	Building Performance Evaluation