Dartington Church of England Primary School

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Building sector	Location	Form of contract	Opened
Schools (primary)	Totnes (Devon)	NEC	2010

Floor area (TFA)	Storeys	EPC / DEC 2013	BREEAM rating
1990 m^2	Single	N/A / C (68) unofficial	N/A

Purpose of evaluation

The School was subject to a two-year programme of monitoring which commenced in June 2011. This work has examined the energy performance, thermal behaviour and occupant response to the School's design: a low energy building, designed with high levels of insulation beyond the standard required by *Part L* of the *Building Regulations*, underfloor heating served by air-to-water heat pumps. Renewable energy sources were incorporated in the form of a photo-voltaic arrays and thermal solar panels. Rainwater harvesting was also a feature delivering grey-water directly to local cisterns.

Design energy assessment	In-use energy assessment	Electrical sub-meter breakdown
No	Yes (2011 - 2013. 2013 quoted)	No

Thermal (gas and heat pumps): 69.9 kWh/m² per annum, electricity: 87.8 kWh/m² per annum. Energy use is biased toward electricity, reflecting the nature of the design that utilises electric heat pumps for space heating. The renewable energy sources contribute to approximately 6% reduction in CO_2 emissions. The design demonstrated some robust features that have performed well, for example the lighting consumption of 7.4 kWh/m² per annum showed the base design of natural and artificial lighting and its control were effective in delivering an energy efficient operation.The photo-voltaic arrays performed consistently, generating 13,000 kWh of electrcity which represents about 8% of the total electricity consumed.

Occupant survey	Survey sample	Response rate
BUS, paper-based	26 of 42	62%

The survye responses showed the building performed well for overall satisfaction and comfort. There were some significant issues, such as perceived overheating, but the design instilled a high level of forgiveness from those people surveyed. The architecture was liked by the occupants but its spacious and sprawling arrangement attracted some criticism for the length of communication routes. Some respondents complained of lack of air movement and odours. The building scored well for natural light but there is some implied criticism of the amount of artificial light. Noise from other spaces was also an issue.

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This report template has been used by BPE teams to draw together the findings of the entire BPE process and to record findings and conclusions, as specified in the Building Performance Evaluation - Guidance for Project Execution (for domestic buildings) and the Building Performance Evaluation - Technical Guidance (for non-domestic buildings). It was designed to assist in prompting the project team to cover certain minimum specific aspects of the reporting process. Where further details were recorded in other reports it was expected these would be referred to in this document and included as appendices.

The reader should note that to in order to avoid issues relating to privacy and commercial sensitivity, some appendix documents are excluded from this public report.

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Executive Summary

Background

Dartington Primary School in Devon was handed over in March 2010. It was designed as series of single storey buildings linked by landscaping connecting the rural exterior to the internal teaching environment. It was arranged in 4 building 'Clusters – 3 housing individual school years and one for administration and assembly with a total treated area of 1,990m^2.

It was conceived as a low energy building, designed with high levels of insulation beyond the standard required by Part L of the Building Regulations, underfloor heating served by air to water heat pumps. Renewable energy sources were incorporated in the form of a photo-voltaic arrays and thermal solar panels. Rainwater harvesting was also a feature delivering grey-water directly to local cisterns. The School was subject to a 2 year programme of monitoring which commenced in June 2011. This work has examined the energy performance, thermal behaviour and occupant response to the School, this report summarises the findings.

Building Delivery

The Architect was appointed under RIBA terms and conditions of engagement whilst the M&E consultant was appointed under the ACE form of contract (Agreement B(2) 2002). This led to a gap in the scope which would prove significant in the way certain events panned out and the effect that had on the resultant performance of the School.

The building was constructed under a NEC form of contract which was not the norm (e.g. JCT) for the Client and they felt this led to poor definition of roles and responsibilities. Interestingly this is contrary to industry views that NEC can be more precise in this area with the safety net of early warning procedures that engage both the professional and contractual team.

A key event was the late value engineering exercise (VE) that was carried out following tender of construction packages at Stage G where 15% savings were sought. This saw the omission of the school-wide BMS which reduced the central control of the heating and ventilating systems to a more basic local control set-up. The critical difference was that the RIBA terms and conditions required the Architect to carry-out any redesign as a result of VE but the ACE defined it as a variation that would warrant additional fees to do. So the outcome was that after the cull of the BMS and metering network from the design the M&E consultant had no input to the re-design thereafter. The consequences of the VE exercise were therefore dealt with largely by the Contractor and Project Manager.

Building Envelope

The insulation standard of the building went beyond that of Building Regulations that pertained at the time of design – Part L 2006. The thermal imaging survey showed that there was a reasonable level of insulation uniformity with few construction cold bridges. However the building envelope has suffered a number of defects since handover, some of which are still being dealt with – e.g. water ingress.

The air tightness tests showed variable results with Cluster 2& 3 being better than the new build standard of 5 m^3/hr/m^2 @ 50Pa whilst Cluster 1exceeded this air permeability achieving levels between 6 to7 m^3/hr/m^2@ 50Pa. It should be noted that the effectiveness of the mechanical ventilation heat recovery system which serves each classroom will be influenced by the air leakage rate which should ideally be less than 3 m^3/hr/m^2 @ 50Pa. The design thermal modelling was based on 5m /hr/m @ 50Pa, but the design team considered that the construction had the potential to achieve less than 3m /hr/m @ 50Pa.

It was found that air leakage paths were more pronounced around roof lights, window and door frames under the depressurisation tests. Service penetrations for such things as electrical conduits and ventilation ducts were a weakness that contributed significantly to the air leakage through the envelope.

Energy Performance

The energy performance for the two test years is given in Table I. It will be noted that the consumption rises in Year 2 by the order of 20%. This was partly due to a more severe winter experieced in 2012/13 where heating degree days were 15% higher than the 20 year average but there was also an underlying trend proably a result of no effective energy management being carried out.

It will be noted that the energy use is biased toward electricity, reflecting the nature of the design that utilises electric heat pumps for space heating. The renewable energy sources contribute to approximately 6% reduction in CO_2 emissions.

The increase in total annual energy consumption in Year 2 is disappointing as there are some basic problems on the HVAC system control and scheduling that were identified in Year 1 that have not yet been rectified. These faults are predominately scheduling and control of the heat pumps that serve the teaching clusters and heating and ventilation in Cluster 4 that are running continously during the winter.

Table I Annual Energy & CO_2 for 2011/12 and 2012/13

	Energy supplied		Renewables		Carbon dioxide emissions (kg of CO_2)
	Gas kWh	Electricity kWh	Thermal Solar kWh	PV kWh	TOTAL
2011/12	113,030	141,765	1,900*	13,288	99,899
2012/13	137,219	170,506	1,786	12,545	120,399

*Estimated value due to late installation of instrumentation.

In Table II degree day corrected energy values for Year 1 are compared to published benchmarks. The benchmarks have limited value as they have been derived from Schools that use conventional fossil fuel heating hence the bias to thermal energy. Looking at the 'common currency' of CO_2 emissions to gauge the performance of the School it surpasses TM46 but is considerably higher than Guide F values.

Table II Comparison with Published Benchmarks for Primary Schools Year 1 results

Unit values	Energy supplied (kWh/m^2*)		Carbon dioxide emissions (kg CO_2/m^2 *)
	Thermal	Electricity	TOTAL
Actual	61.0**	69.5	49.5
TM46	150.0	40.0	51.1
CIBSE Guide F	91.0	12.0	24.3

*Treated floor area is assumed to be 1,990m^2

** Cluster 4 gas boiler plant energy consumption - heat pump and electric flow boiler energy is included under electricity

Considering the specific performance of the School it is clear that it is under achieving but it does have the potential of being an exemplar. The design demonstrated some robust features that have performed well:

- The annual lighting consumption 7.4 kWh/m^2 shows the base design of natural and artifical lighting and its control are effective in delivering an energy efficient operation with the occupants scoring lighting above the national benchmark in occupant satisfaction survey.
- The annual small power consumption is low at 2.0 kWh/m^2 showing that mangement of use is effective.
- There is good control of the electric flow boilers which supplement the air source heat pumps indicating only 6% of the total plant consumption.
- The annual mechanical ventilation consumption is low at 3.1 kWh/m^2 which is more of a reflection of the staff's preference for natural ventilation even during the depths of winter.

The school performs reasonably well against the TM46 benchmark which translates into a C 68 operational rating but is under performing against its potential. If control and scheduling of HVAC are 'tightened' up a category B DEC is practically achievable.

Renewable Energy

The renewable energy sources in the School have made significant contributions to its performance:

Photovoltaics

The photo-voltaic arrays have been consistent performers generating 13,000kWh of electrcity which represents about 8% of the total electricity consumed. In total there are 114m^2 of polycrystalline arrays with a peak output of 14kWp giving 114kWh/m^2 of PV panel. Interestingly the months of April and May have shown high outputs reflecting the impact of solar altitude and roof pitch. One would have expected the symmetry effects of solar geometry to also show high outputs in August and September but this not so. The output from the array will be affected by ambient temperature and this difference in performance may be explained by the higher ambient temperatures experience in late summer early autumn compared to spring.

Thermal solar

The 6m^2 of of flat plate collector contributes to the DHWS in Cluster 4 annual heat output has been monitored at 1,786kWh which represents 12.5% of the DHWS heat for this Cluster . The panel output is 293kWh/m^2 of collector area. If the mean incident annaul solar irradiation is of the order of 1000kWh/m^2 for the site location this represents a thermal efficiency of approximately 30% which is below what might expect for this type of collector – 40 to 50%. The reasons for the discrepency are likely to be losses from the collector and distribution pipework and attenuation of solar radiation due to dirt build up on the glazed facing plate. It is also evident from the annual profile there was very little output during the period November to February.

Energy Costs

The electricity tariff that the School is running on is high. If we compare with average rates for small non-domestic consumers we find the unit cost of electricity the School is currently paying to be significantly higher:

Small non-domestic consumer average for Q2/2013*	10.96p/kWh
Dartington School	15.36p/kWh

The School was initially signed up to a provisional tariff rather than to the DCC bulk supplier due to delays in getting the agreement in place before practical completion. This provisional arrangement was only to last for the first 18 months of operation it would be prudent to review the tariff with DCC as there are significant savings that could be made. The build-up of standing charge should also be considered in light of findings from the monitoring work e.g. the School maximum demand was found to be approximately 80kW this should be compared to the assumption used in setting the supply availability charge.

Gas in 2013 was charged at 3.118p/kWh which was increased in April to 3.475p/kWh. This compares to the average for a small consumer of in Q2 of 2013 of 2.87p/kWh. Whilst this is closer to the average gas cost it would be worth considering both in a tariff review.

Occupant Satisfaction

The BUS performance indices show the building is in the upper part of the dataset for overall satisfaction and comfort. There are clearly some significant issues on comfort e.g. Cluster 4 overheating, but the design and the site location have instilled a high level of forgiveness from those people surveyed.

The architectural design is liked by the occupants but its spacious and sprawling arrangement has attracted some criticism of the length of communication routes.

The building scores poorer than the national benchmarks on dryness of air in summer with goes against a general trend found in buildings where outside air moisture content actually increases in summer and excessive humidity is often the problem. This might be allied to other poor scoring parameters which are the feeling of a lack of air movement and odours.

The building scores well for its utilisation of natural light but there is some implied criticism of the amount of artificial light which scores lower than the benchmark. However control of lighting is liked, scoring at the 91st percentile of the dataset.

Noise from other spaces is also picked up as being an issue where it was rated poorly at the 5th percentile in the data set.

Environmental control

The results from the thermal environment monitoring show that:

- Summertime temperature distributions in teaching clusters were reasonable only exceeding 25°C for less than 4% of occupied hours – occupants response was equal to the national benchmark
- Wintertime temperature control was effective - occupants scored the space above the national benchmark in the occupancy survey

Cluster 4 was cited by the staff as having thermal comfort problems in terms of excessive temperature and this was borne out by the data which showed a shift in the distribution with mean lying at 23°C -24°C and 7% of occupied hours in excess of 26°C.

- Staff room temperature profiles indicate the plant is operating out of hours and at high set points – in winter this is around 23°C. The plant should be returned correctly scheduled pattern of operation with set points lowered to 21°C to give a fresher feel to the spaces.

The level of ventilation should also be reviewed in Cluster 4 as the lack of rapid ventilation will be contributing to the overheating experienced. Rapid ventilation to purge spaces that experience high heat gain should moderate temperature swings in summer. There is provision for rapid ventilation with openable windows but whether this can be introduced in winter months without the creation of discomfort due to cold draughts needs to be reviewed. In winter the control set-points adjustments should restore a better temperature distribution in the staff spaces.

Poor performance of the underfloor heating was noted in feedback from staff. The monitored data tends to show that comfort conditions were generally maintained so staff may have been referring to the occasional incidents where the floor coils air locked but worked satisfactorily after venting.

It was also observed from the monitoring that the heating systems were operating on a 24/7 basis. The scheduling of the heat pump should be reinstated with an appropriate set back condition of say 17°C. The teaching areas have a lightweight thermal response which means that temperature recovery would be achieved within one or two hours of preheat start as was seen from temperature monitoring of the spaces..

The thermal imaging did reveal that there were certain sections of the underfloor loops that were ‘dead’ suggesting that there was no flow in these sections – manifolds should be checked to see if this is due to fouling, air locking or simply valved-off.

Action Plan

An action plan to improve the buildings performance has emerged from the monitoring work. This has been discussed with the School to get these affordable and effective measures implemented as soon as possible:

1. Heat pump controls - the machines are showing continuous operation in cold weather. The Nibe SMO 10 controller has the facility to operate in a set-back mode and to accommodate vacation periods.
2. Review the time schedule controlling the kitchen AHU and extract fan which appears to be on continuously.
3. Re-location and securing of the teaching space thermostats that are in the receipt of cold outside air from external glass access doors which gives a false reading and in some cases are at a height where they can be adjusted by the children.
4. Cluster 4 suffers from complaints of overheating which is borne out from our space temperature monitoring. The Trend controller needs to be re-commissioned in order to revert back to a set-back to of say 17°C rather than the current set point of 20°C when the building is unoccupied.
5. Energy management – there is a good provision of metering in the electrical distribution with a communications network back to the Schneider 3500 controller - however this is

not being used effectively. Monitoring and targeting software can be applied in order that a tighter rein can be kept on energy use and waste identified and corrective action be put in place. The plan is to incorporate both gas and water metering to this monitoring network. Arup will work with the School to set up a more effective energy management arrangement.

6. Both gas and electricty tariff should be reviewed as they both appear high when compared against Government issued yardsticks for a small non-domestic user.

1 Introduction and Overview

1.1 Background

Dartington School is a new build state primary school, on the outskirts of Totnes, at Dartington in Devon. It is a 'Federation' School funded by the County Council. It enjoys satisfactory Ofsted ratings, is very popular with parents, and as a member of the National College for School Leadership, gives guidance to other schools and teachers on educational techniques. Its strengths are environmental subjects and it is an 'Ecoschool', with a wealth of opportunities from its location in the countryside, art and music.

The construction is part of a '10 year plan' by the school to provide a new building and was handed over in March 2010.

The school is constructed of a timber panel, timber clad, self-supporting structural system with 4 separate groups of buildings or 'Clusters'.

- Cluster 1 is four rooms; a double room nursery and two rooms for Reception
- Cluster 2 is six classrooms for Key Stage 1 (years 1, 2 and 3)
- Cluster 3 is six classrooms and a cookery room for key Stage 2 (Years 4,5,and 6)
- Cluster 4 contains all the common facilities consisting of a School Office, teacher's and Head Teacher's rooms, multipurpose hall, gym, kitchen and music room.

The Head Teacher was very enthusiastic to host the Building Performance Study. Her objective was to improve the performance of the building, and to focus attention on completing defects with the added advice of the Building Performance (BP) Team to help her deal with the contractor and local authority project manager.

The old school was a collection of temporary buildings and porta-cabins, which according to the Head Teacher was the precedent for the current lay-out as a series of separate school buildings within a garden landscape. The background to the new building was a strong campaign mounted by the school for a striking environmental building which led to the appointment of White Design as architects.

The initiative for carrying out the BPE application came from the Architect and the School who were keen to resolve various problems which had arisen within the school since opening; these appeared to be a continuing series of defects which had not yet been resolved. The Arup Building Performance team agreed to make a TSB application to analyse these issues, to aid the School in understanding the operation of their systems, and to provide an independent view on the source of the problems. This report records the results from a 2 year building performance evaluation project funded as part of the TSB's programme of work.

2 Details of the building, its design, and its delivery

2.1 Building Design

The design was conceived to connect the external rural environment with the internal teaching spaces in a series of modular constructions that would be linked by landscaping rather than be brought together in a single mass. The primary objectives of the design were to be energy efficiency and fully sustainable.

The school consists of four separate single storey clusters – each teaching cluster was assigned to take a specific school years, see Table 1. Cluster 4 contains the administrative and communal spaces such as sports hall, offices, staff room, etc. Typical plans and elevations are shown in Figure 3, site arrangement is shown in Figure 4 and elevations and interiors are shown in Figure 1 and Figure 2.

The design philosophy which was heavily influenced by the Brief and that was to create a village environment – pavilions in the landscape. The architecture is liked by the staff describing it as a "great and inspiring place to work with wonderful light".

Figure 1 Cluster 2 Elevations Viewed from the East

Figure 2 Interior View of Classroom

Table 1 Building Area Details

Cluster	Description	Treated floor area m2
1	Foundation stage, nursery, reception classrooms and toilets	319
2	Key stage 1, classrooms, resource, group rooms and toilets	378
3	Key stage 2, classrooms, resource, group rooms and toilets	532
4	Administration, staff room, sports hall, kitchen etc.	760
	Total Gross Internal	1,990

The teaching clusters were all prefabricated in a timber construction, are square in plan and have high floor to ceiling heights. With view up into the pitched roof vaults, day- lighting has been achieved with north lights and tall glazing to give views across the countryside.

The building is constructed entirely of timber from sustainably managed forests with little steel or concrete used in the above ground structure and cladding. Almost no steel or concrete was used in the structural frame or envelope. The envelope is built almost entirely of timber or timber products, sourced from sustainably-managed forests. Its structure is shown in cross-section in Figure 6 – note that all insulation on the project was made from recycled timber pulp.

Figure 3 Typical Floor Plan & Elevation of the Teaching Cluster

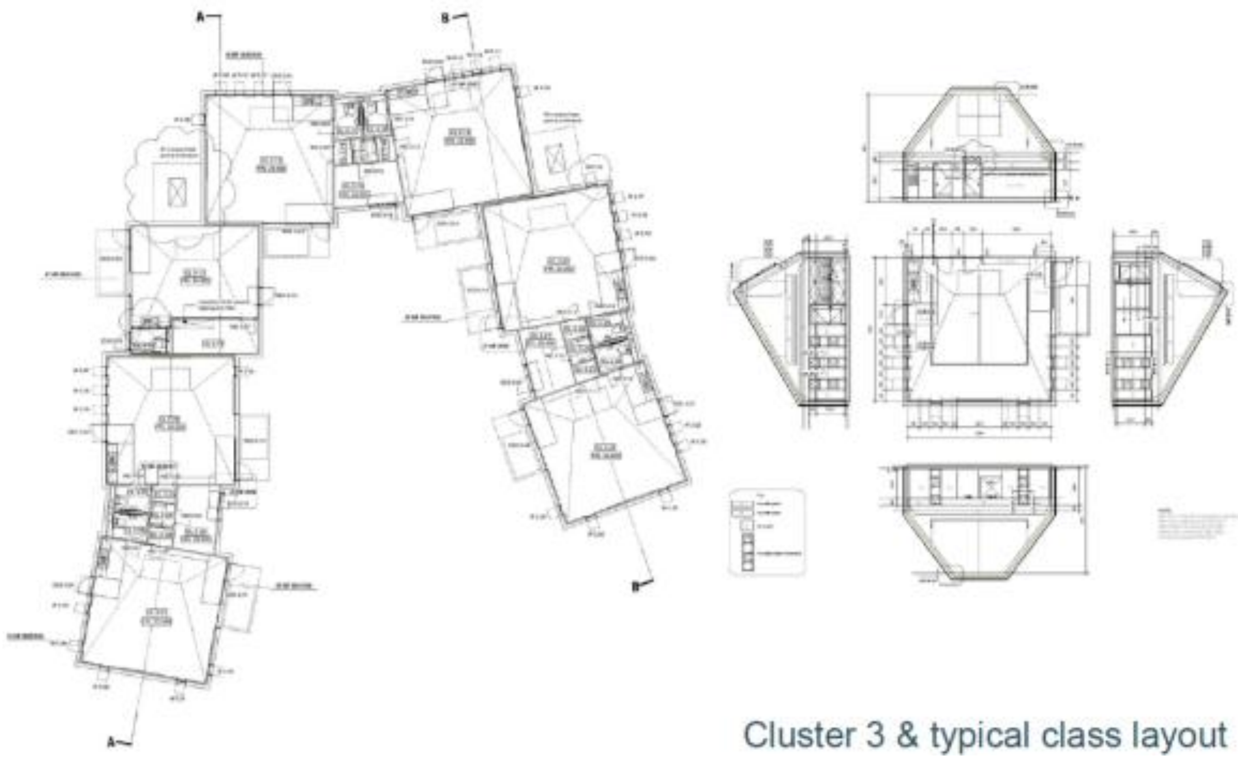


Figure 4 General Site Plan

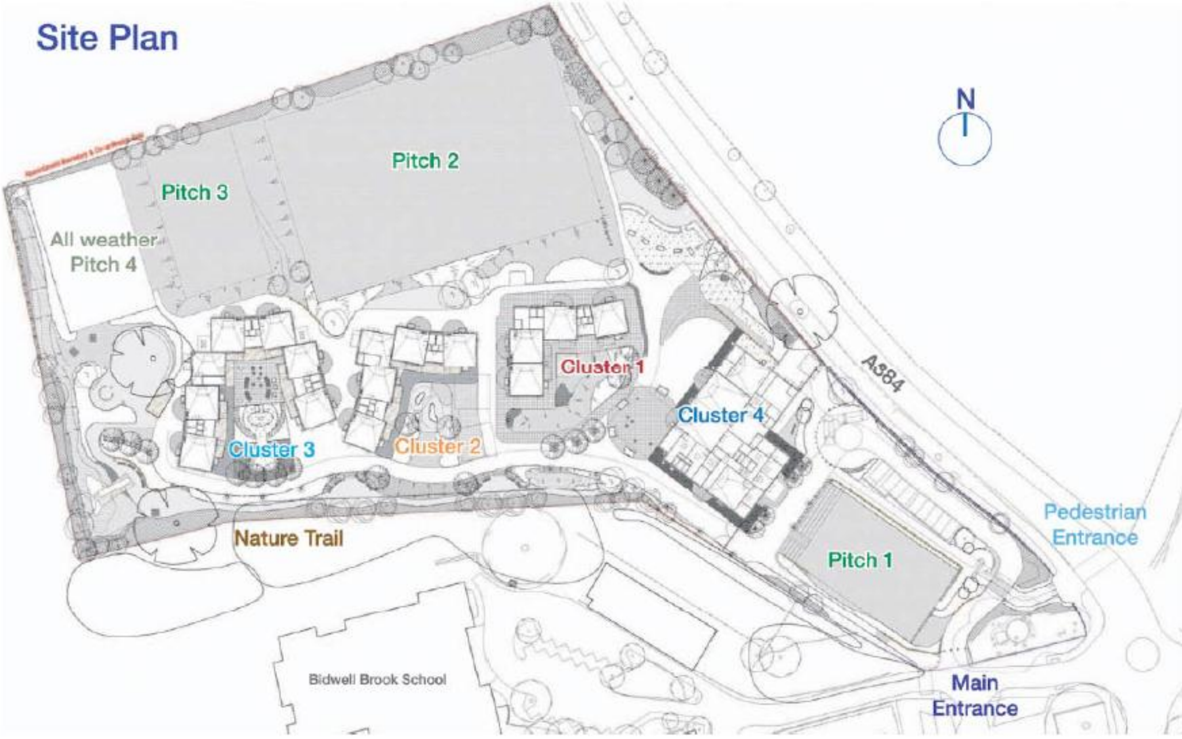
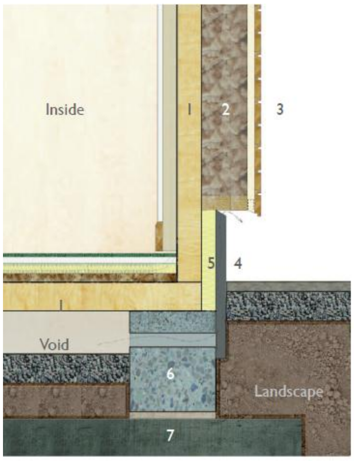


Figure 5 Aerial View of the Site

The Building thermal characteristics went beyond the minimum standards required by Building Regulations 2006 as shown in Figure 6. The construction technique for the building is an innovative solid timber construction method developed in Europe. This method involves prefabricating edge-glued and solid cross-laminated timber (CLT) boards off site and then fitting the pieces together once they have been transported to site. This method reduces waste as all offcuts can be recycled at the manufacturing plant.

Figure 6 Insulation Standards of the Building Fabric



1. 85mm Solid timber panel
2. 160mm Woodfibre insulation
3. 22mm Sweet chestnut cladding on 25mm SW treated battens.
4. Onduline corrugated board & RIW protection board.
5. Rigid below ground insulation
6. Concrete ground beam (vented)
7. Pre-cast concrete manhole rings (backfilled)

Facade Buildup

Element	'As-built' U (W/m^2 K)	Building Regs 2006 (W/m^2 K)
Wall	0.19	0.35
Pitched roof	0.17	0.25
Flat roof	0.20	0.25
Floor	0.20	0.25
Windows	1.2	2.20

The design employed a number of low carbon and renewable technologies:

- Air source heat pumps serving a floor warming system
- Mechanical ventilation with heat recovery for wintertime
- Rainwater harvesting for a de-centralised grey water recovery system
- Photo-voltaic arrays on clusters 2, 3 &4.
- Thermal solar water in cluster 4
- Sustainable drainage using drainage strategy

2.2 Building Procurement

The project was administered by the Devon County Council project officer who appointed Norfolk Property Services (NPS) as Employers agent/project manager. NPS used a separate contract for the appointment of the architect through a traditional appointment and the project was procured using New Engineering Contract (NEC).

The project team consisted of the following:

Architect, design team leader, landscape architect:	White Design
Project manager:	NPS
Quantity Surveyor:	Ridge
M&E engineer:	Arup
Structural engineer:	Rambol
Main contractor	Interserve
M&E sub-contractor:	NG Bailey
Timber frame engineer:	Eurban;

NPS were employed to carry-out a package deal on a fixed fee. White Design Architects were appointed after a competition and adopted the pod concept. Interserve were appointed as management contractor at Stage D by written submission and interview with all sub-packages sub-tendered competitively.

The procurement method involved separate contracts with the design team under standard RIBA and some under ACE conditions. A critical issue was that White Design were appointed under RIBA terms and conditions whilst Arup were appointed under ACE form of contract (Agreement B(2) 2002). As a consequence there was a gap in the scope highlighted by the duties for re-design following value engineering (VE). Here the RIBA terms and conditions required the consultant to cover the re-design after VE exercises and ACE has it as additional duties that need to be paid for. The consequences of the VE exercise were therefore dealt with largely by the contractor.

It was noted by DCC that the normal approach for a project of this type would have been design and build or private finance initiative type contracts and they cited the NEC form of contract as being part of the causes of problems. Paradoxically the NEC form of contract is considered by those in the industry familiar with its application to be precise in defining roles and responsibilities with a safety-net of early warning procedures that engage both the professional and contractors' teams.

Interserve priced the packages which were validated by Ridge. Following tender, cost reductions of approximately 15% were sought to meet the target budget of £7m. These reductions were made on such elements as early procurement of the Swiss timber units, landscaping and elements in the M&E scheme. A critical omission in the Stage G (Tender Documentation) value engineering (VE) exercise was the removal of a school wide BMS system and the metering communication network. There is no record of a re-design of the systems to compensate for these changes.

These omissions have emerged as major issues in the waste of energy through the poor control of key items of plant and equipment such as the heat pumps and kitchen ventilation systems.

2.3 Key findings from the Procurement Process

1. It was claimed by the Client that the NEC approach as applied in this instance failed to clearly define all roles and responsibilities which led to difficulties in controlling events in the project delivery. It clearly was a new approach to procurement for some in the team and perhaps it was their unfamiliarity with it that contributed to problems. It is difficult to see that the building defects and resolving them that emerged since completion would have been any different under another form of contract.
2. There was a gap in scope between the terms and conditions of the appointment for the Architect and those under which the M&E engineers were contracted. This meant that the fall-out from the VE exercise was not adequately dealt with. According to the designers, there was a failure to redesign an alternative control system when as a result of the Stage G value engineering, the school wide BMS was removed. There appears to be an absence of documentation about the replacement systems.
3. Design documentation should include a minimum controls strategy narrative which anticipates any future value engineering and which specifies reporting requirements for the metering of energy and water.
4. It is important that a 2 year warranty with 2 years maintenance contract via the main contractor for all systems should form part of the procurement contract

3 Energy & Water Performance

3.1 Annual Energy Consumption

The annual energy consumption for the Year 1 & Year 2 is shown in Table 2 and is also expressed per m^2 of treated floor area in Table 4. The weather severity normalisation is detailed in Table 3 and comparisons with benchmarks are shown in Table 4

The electricity generated by the PV in the monitoring period was13,288kWh which represents 5.4 kWh/m^2. This was 6% lower during the period 2012/1. Solar water heating was monitored at 1,786kWh in the period 2012/13.

The energy consumption for Year 2 shows an increase in gas of 21% and 20% on electricity compared to Year 1. It will be noted in Table 3 Heating Degree Days for South West, that the heating degree days as a measure of weather severity showed Year 2 to be 20% more severe than Year 1. Since the School is using electric heat pumps for Teaching Clusters 1 to 3 and gas heating for Cluster 4, this explains some of the increase in consumption although not all.

Table 2 Annual Energy & CO_2 for Year 1 (2011/12) and Year 2 (2012/13)

	Energy supplied		Renewables		Carbon dioxide emissions (kg of CO_2)
	Gas kWh	Electricity kWh	Thermal Solar kWh	PV kWh	TOTAL
2011/12	113,030	141,765	-	13,288	99,899
2012/13	137,219	170,506	1,786	12,545	120,399
Change	+21%	+20 %	-	-6%	+20.5%

Table 3 Heating Degree Days for South West

	HDD @15.5°C	HDD 20 Year Average	HDD Correction factor
Year 1 (2011/12)	1676	1757	+4.8%
Year 2 (2012/13)	2034		-13.6%
Difference	+21%		

HDD – heating degree days (base 15.5°C)

Applying the HDD correction to the space heating components of energy use we see the School performs well against the TM46 (DEC benchmark) but is significantly higher than the CIBSE Guide F School benchmark. Examining the School against the CIBSE benchmark the use of gas and electricity biased differently – the benchmark gas use is higher and electricity is an onerous standard at 12kWh/m^2.

Table 4 Annual Energy in kWh/m^2 & CO_2 compared to Benchmarks 2011/12 (Degree Day corrected)

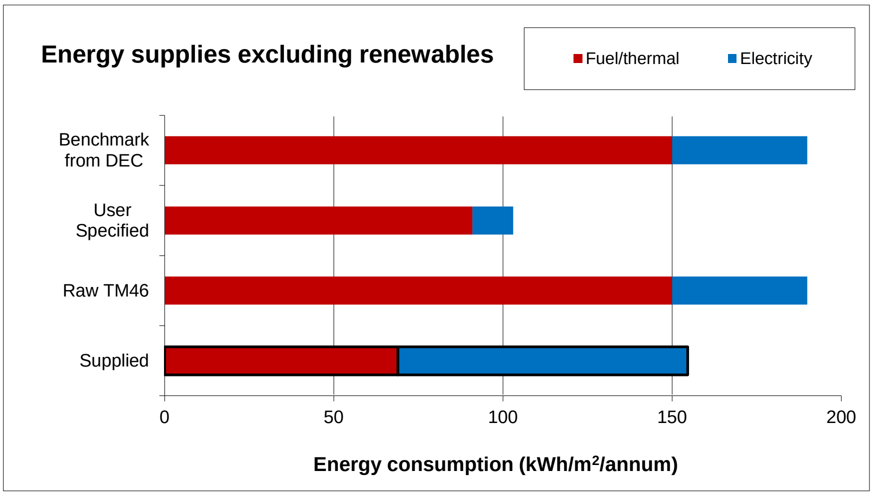
Unit values	Energy supplied (kWh/m^2*)		Carbon dioxide emissions (kg CO_2/m^2 *)		
	Thermal	Electricity	Thermal	Electricity	TOTAL
Actual	61.0	69.5	11.3	38.2	49.5
TM46	150.0	40.0	29.1	22.0	51.1
CIBSE Guide F	91.0	12.0	17.7	6.6	24.3

Table 5 Annual Energy in kWh/m^2 & CO_2 compared to Benchmarks 2012/13 (Degree Day corrected)

Unit values	Energy supplied (kWh/m^2*)		Carbon dioxide emissions (kg CO_2/m^2 *)		
	Thermal	Electricity	Thermal	Electricity	TOTAL
Actual	63.2	82.3	12.3	47.6	59.9
TM46	150.0	40.0	29.1	22.0	51.1
CIBSE Guide F	91.0	12.0	17.7	6.6	24.3

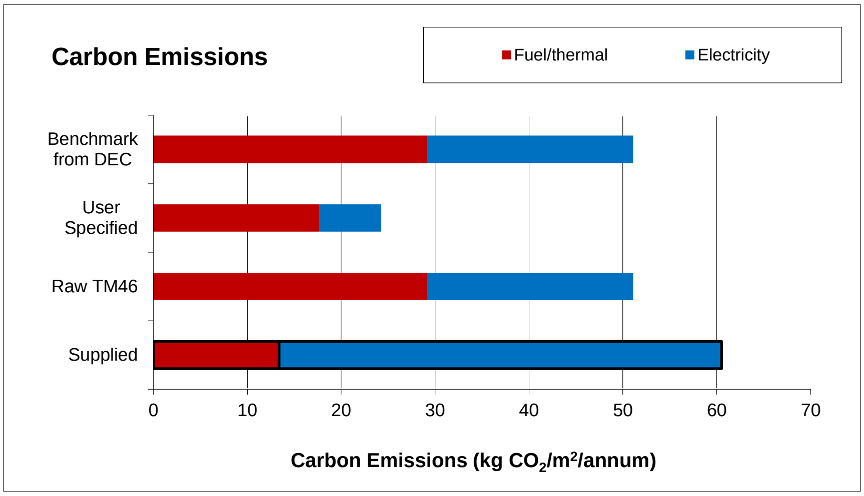
*Gross Internal Area = 1,990m^2
Carbon Factors Gas = 0.195 kg CO_2/m^2 Electricity = 0.550 Gas = 0.195 kg CO_2/m^2

Figure 7 Comparison of Actual Energy with Benchmarks for 2012/13 (TM22 extract)



Note 'Supplied'- as monitored 'User Specified' benchmarks are taken from CIBSE Guide F data.

Figure 8 Comparison of Actual CO2 with Benchmarks (TM22 extract)



The energy use is biased toward electricity usage as a large proportion of the building heating is provided by air to water heat pumps. As a consequence the gas usage is low when compared to these benchmarks. If this is converted to CO_2 the school performs reasonably well against the TM46 benchmark which translates into a C rating 68 but is under performing against its potential. If control and scheduling of HVAC are ‘tightened’ up a category B DEC is practically achievable.

3.1.1 Renewable Energy

The contribution from the renewable elements of the building design are summarised in Table 6. The electrical energy produced by the photovoltaic arrays was measured through the online remote monitoring system. The heat produced by the thermal solar panels was monitored using a data logger measuring flow and return water temperatures to the collectors integrated with water mass flow to give heat quantities.

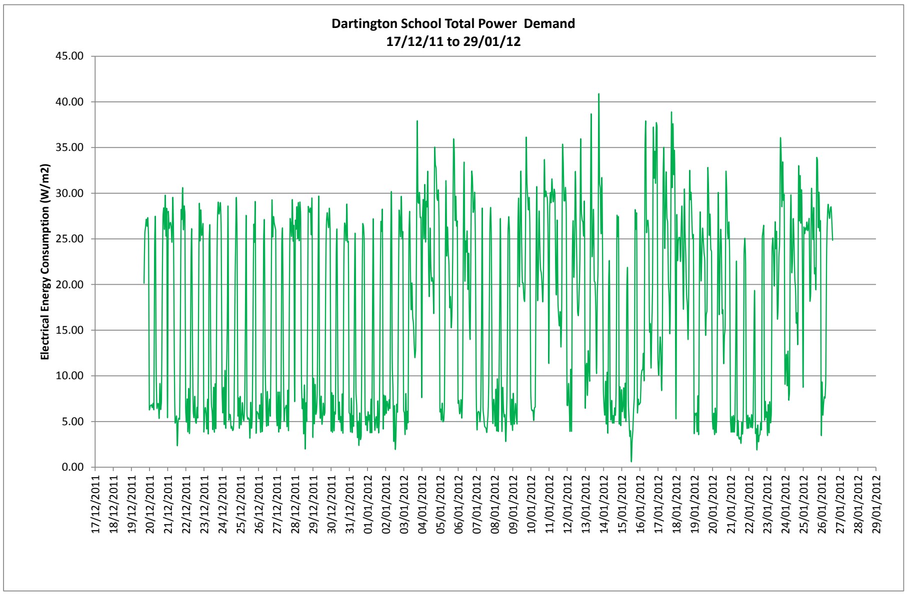
Table 6 Renewable Energy Contributions

Renewable Source	Annual energy Generated in kWh	% of total School elec/heat	Output/m2 of array Panel kWh/m^2
Photo-voltaic arrays	13,288	7.2%	117
Thermal Solar Panels	1,786	<1% (12.5% of Cluster 4 DHWS heat)	298

3.1.2 Electrical Maximum Demand

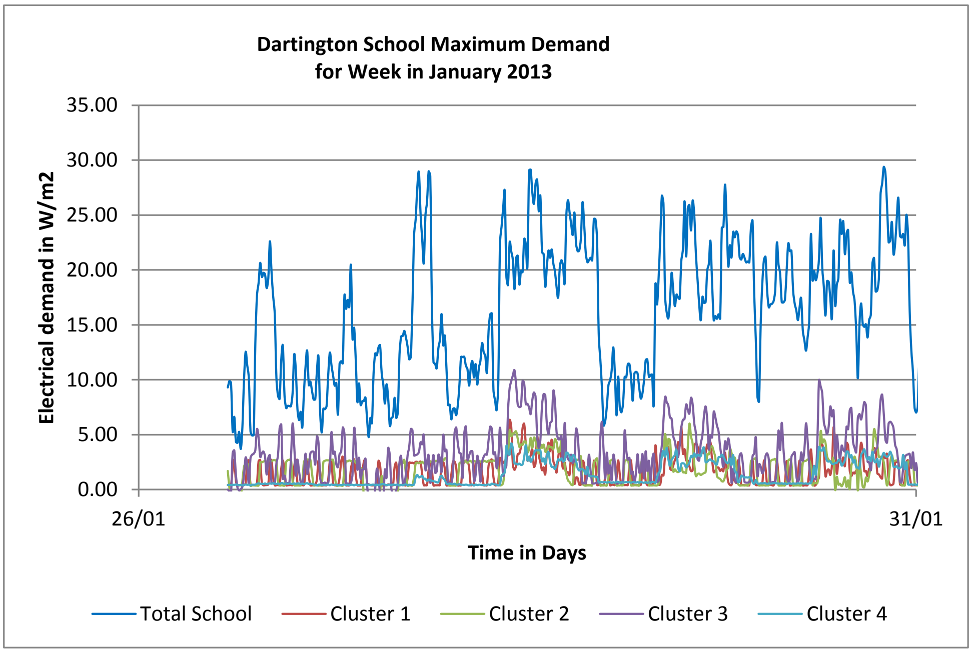
The School maximum demand profile is shown in Figure 9 and is expressed in W/m^2 of treated floor area at 1,990m^2. The peak load is approximately 82kW or 41W/m^2 which reduces to an unoccupied demand of 10 kW or 5 W/m^2. The demand is influenced by the operation of the electric air to air heat pumps which can be seen to be operating over the Christmas/New Year holidays. The time switching of the machines needs to be reviewed in this respect - this is discussed in more detail in the heat pump review.

Figure 9 Building Maximum Demand for Wintertime Operation



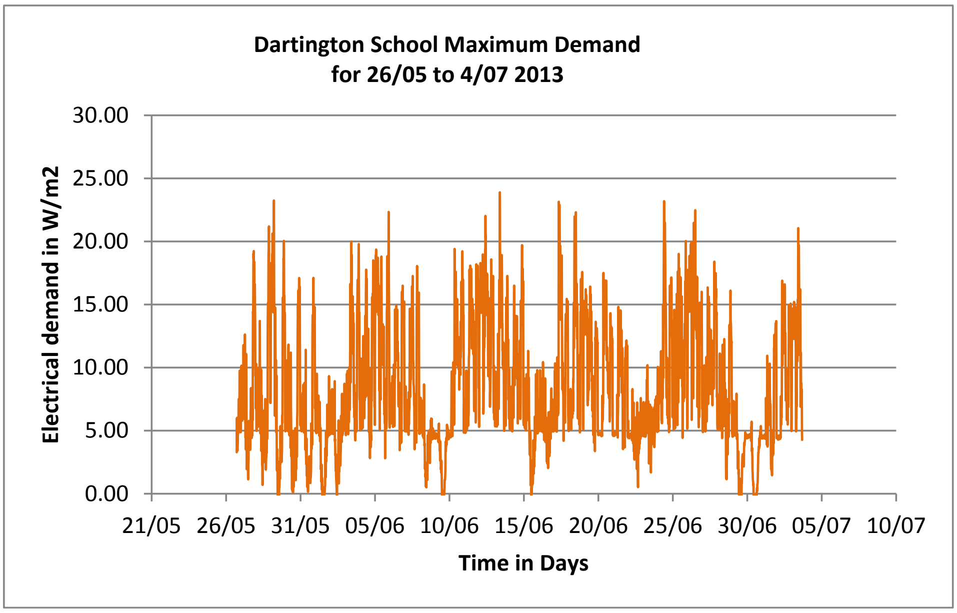
The components of the maximum demand are illustrated in Figure 10. The major contribution is from cluster 3 being the largest of the Teaching Clusters and being served by heat pumps. The profiles are similar for the teaching Clusters, however Cluster 4 is low because this is served by gas heating. The weekend fell on 26th& 27th and this data shows that where the Cluster 4 (Admin) demand reduces to less than 1W/m^2 the Teaching Clusters are still showing a significant demand caused by the lack of time switching of the air source heat pumps.

Figure 10 Building Maximum Demand in Wintertime 2013 showing Demand Components (Treated Area 1990m2)



In summertime, heat pumps were off and the predominate load is lighting. With active control of lighting in response to improved day-lighting the demand halves to approximately 20W/m^2, see Figure 11.

Figure 11 Building Maximum Demand for Summertime Operation



3.1.3 Energy Costs

The School electricity is supplied by EDF on a monthly single rate tariff charged at 15.36p/kWh the monthly standing charge is £140/month, see Table 7. For the energy used in 2012/13 this works out at £27,870 for the year. This is a high cost and there improvements in operation that will reduce this.

Table 7 Electricity Costs for 2012/13

Electricity	Units	Cost
Monthly Standing charge; @ £140/month	12	£1,680
Units; @ 15.36p/kWh	170,506kWh	£26,190
Total		£27,870

The tariff is also high. If we compare with average rates for small non-domestic consumers we find the unit cost of electricity to be significantly higher:

Small non-domestic consumer average for Q2 2013*	10.96p/kWh
Dartington School	15.36p/kWh

The School was initially signed up to a provisional tariff rather than to the DCC bulk supplier due to delays in getting the agreement in place before practical completion. This provisional arrangement was only to last for the first 18 months of operation it would be prudent to review the tariff with DCC as there are significant savings that could be made. The build-up of standing charge should also be consider in light of findings from the monitoring work e.g. the School maximum demand was found to be approximately 80kW this should be compared to the assumption used in setting the availability charge.

Gas in 2013 was charged at 3.118p/kWh which was increased in April to 3.475p/kWh. This compares to the average for a small consumer of in Q2 of 2013 of 2.87p/kWh*. Whilst this is closer to the average gas cost it would be worth considering both in a tariff review.

*Source DECC Quarterly Energy Prices June 2013

Table 8 Gas Costs for 2012/13

Gas	Units	Cost
Monthly Standing charge;	none	£0
Units; @ 3.475p/kWh	137,219kWh	£4,768
Total		£4,768

3.1.4 TM22 Analysis

A TM22 analysis has been completed for both years to analyse the energy usage of different systems within the school. This analysis is important to see how the systems are currently being used and what recommendations can be made to reduce the overall energy consumption of the clusters. In this analysis, metered electricity and gas has been analysed and the data compared with an estimated state at which the clusters should ideally be operating.

The analysis found that many of the systems were consuming more energy than expected over the measured periods. More detailed analysis revealed that many of the systems were in operation inappropriate times such as overnight or over the school holidays. The analysis was therefore amended to take this into consideration so that the metered data was compared to an estimated usage of the system during this extended time period.

Further analysis was carried out into the usage profiles of the systems so that waste periods could be identified and eliminated.

Table 9 TM22 Analysis of End Use Loads for Years 1& 2

	Year 1 (2011/12)		Year 2 (2012/2013)	
System	**Gas ($kWh/m^2/year$)**	**Actual electricity ($kWh/m^2/year$)**	**Gas ($kWh/m^2/year$)**	**Actual electricity ($kWh/m^2/year$)**
Space Heating	35.7	20.3	47.8	28.7
Hot water	13.3	5.3	13.0	5.6
Refrigeration		6.3		7.7
Fans		3.0		3.1
Pumps		2.5		4.3
Controls		0.4		0.4
Lighting (Internal)		5.9		7.4
Lighting (External)		7.9		7.4
Small Power		1.8		2.0
ICT Equipment		0.6		0.6
Catering - Central	9.0	9.4	9.0	9.4
Catering - Distributed		0.0		0.0
Miscellaneous		5.2		11.1.
Total	**58.0**	**68.6**	**69.9**	**87.8**
Metered building electrical energy use		75.9		92.0
Difference between metered and modelled electricity		-10%		-5%

The heat pumps were showing an annual energy consumption of approximately 20 kWh/m^2 in Year 1which if considered over the Cluster 1, 2 and 3 treated areas (1,229m^2) would result in a heating index of 32kWh/m^2. If we translate that into what the consumption would be if the heat was delivered by a conventional gas fired boiler then we find the teaching spaces have a heating consumption of:

$$Q_{\text{gas equiv}} = 94 kWh/m^2$$

Assuming SEER = 2.5 (seasonal heat pump CoP =2.5 see section 6.5)
Boiler Seasonal Efficiency = 86%

The space heating consumption in terms of delivered heat is similar to the benchmark given for best practice in Table 10. Given the known inefficiencies in the way in which the heat pumps are run, the school could easily be an exemplar as regards space heating energy use.

The Teaching Clusters are well insulated and there evidently significant energy waste occurring on the heat pumps, not least the absence of time-switch control and the location of thermostats adjacent to external sliding doors. The space heating consumption in Table 9 also shows the gas that is used for heating Cluster 4 at 48 kWh/m^2. This has been expressed in terms of the total treated floor area for the entire school. Year 2 shows an increase to 28kWh/m2 but the weather during this period was 20% cooler than the 20 year average explaining some of this difference.

If this is considered against the floor area of Cluster 4 – 760m^2 the index would then be 125kWh/m2 which is excessive for a building with these thermal characteristics. Adjustment of the control of the boiler plant particularly scheduling to match actual occupancy and space temperature set-points set to lower recommended levels should be carried out.

End use energy targets are shown in Table 10. The Schools lighting energy consumption is about half that of typical practice and lower than best practice benchmarks reflecting the effectiveness of the lighting system control.

The Schools use of small power also is considerably better than these best practice indicators even with the inclusion of mechanical ventilation fan energy in the assessment.

Table 10 End Use Energy Benchmarks

Gas	**Good Practice**	**Typical**
	kWh/m2	kWh/m2
Heating	91	125
DHWS	25	35
Catering	9	13
Total	**126**	**173**
Electricity	**Good**	**Typical**
	kWh/m2	kWh/m2
Lighting	10	14
Small power + other	8	11
Catering	2	3
Total	**20**	**28**

Ref (Energy Consumption Guide for Schools ECG073 Carbon Trust)

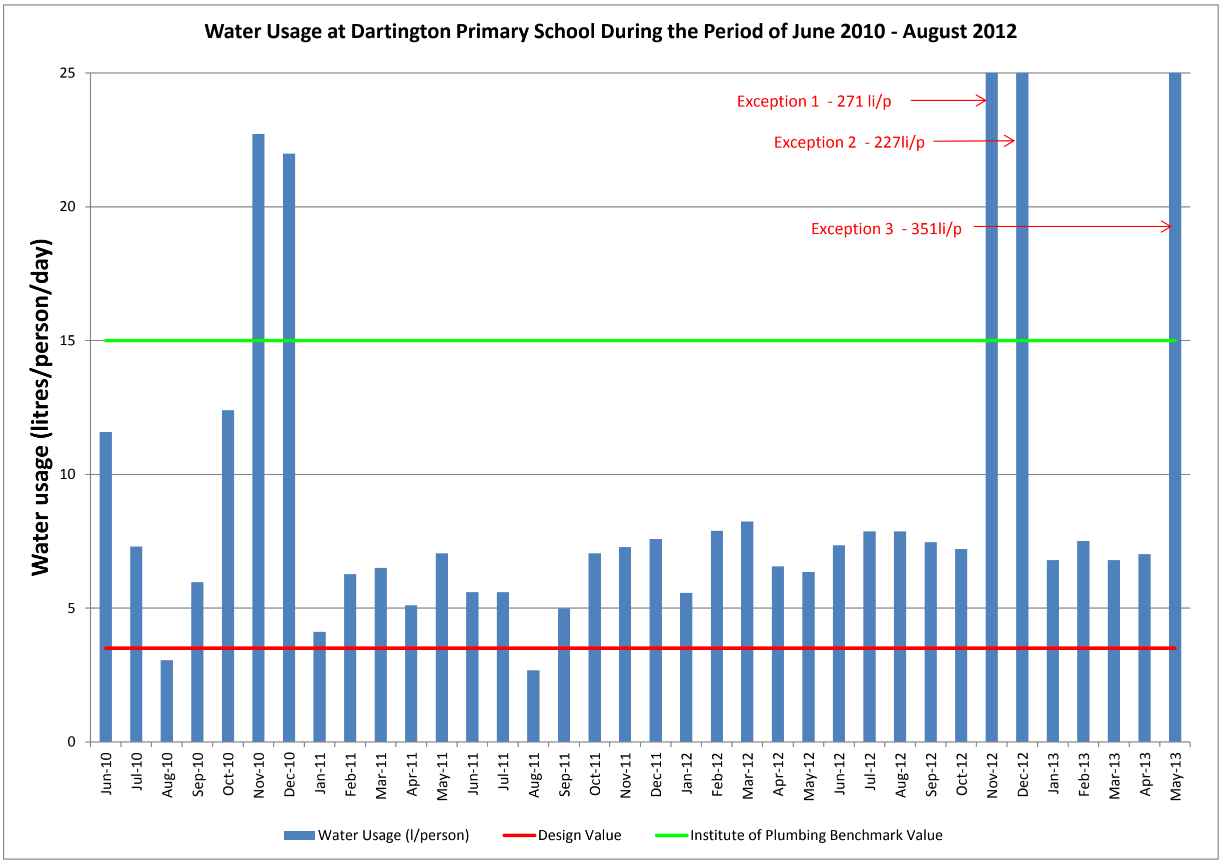
3.2 Water Consumption

Data has been collected for Dartington School from the metering system located in the neighbouring school Bidwell Brooke as the schools share the incoming water main. The graph below shows that the water consumption of the school is slightly above the design value of 3.5 litres/person/day, see Figure 12. The total daily consumption for this period varies between 5 and 8 li/p/day. There are three ‘exceptions on the graph but other than this the usage does not exceed, and is well below the Institute of Plumbing (IoP) Benchmark Value for primary schools, of 15.0 litres/person/day.

The first exception was caused by a burst pipe in the winter of 2010. The second exception was caused by a fault with the sprinkler tanks which caused the tanks to constantly discharge over a number of days in November 2012. The exception in May 2013 was the result of 8 water tanks being drained down, cleaned and chlorinated. The overflowing of the sprinkler tanks needs to be monitored closely by the school - whilst it is sporadic the water use is a large consumption. The rainwater recovery is having some beneficial effects reducing water consumption to below the IoP benchmark.

What should be investigated is the August water consumption although this month in normally below the design criterion of 3.5 li/p/day it is at a time when the school is not used. This quantity of water use is consistent at approximately 2.5 li/p/ for August 2010 and 2011 and could be waste that could be prevented.

Figure 12 Water usage at Dartington Primary School during the period of June 2010 - August 2012



3.3 Conclusions and key findings

3.3.1 Energy Consumption

The School has an energy consumption that is higher than the CIBSE Guide F benchmark but marginally better than the DEC benchmark yielding a DEC of category D. The application of air source heat pumps for a large proportion of the School means energy split between fuel and power is biased toward a higher electricity consumption.

The School is served with a number of renwable energy sources

- photo-voltaics which delivers a consistent consumption of approxiamtely 7 kWh/m^2 per year
- thermal solar generating approxiamtely 1kWh/m^2 of heat for the DHWS

There are a number good stories which can be seen from the monitoring work of the School :

- The lighting consumption 7.4 kWh/m^2 shows the base design of natural and artifical lighting and its control are effective in delivering an energy efficient operation with the occupants scoring lighting above the national benchmark in occupant satisfaction survey.
- Small power consumption is low at 2.0 kWh/m^2 showing that mangement of use is effective.
- There is good control of the electric flow boilers which supplement the air source heat pumps indicating only 6% of the total plant consumption.
- Mechanical ventilation is low at 3.1 kWh/m^2 which is more of a reflection of the staff's preference natural ventilation even during the depths of winter.
- Kitchen AHU should be scheduled to match occupancy better there is evidence that it is running out-of hours and leading to significant waste.

3.3.2 Energy Tariffs

Both gas and electricty tariff should be reviewed as they both appear high when compared against Government issued yardsticks for a small non-doemstic user.

3.3.3 CO_2 emissions

The CO_2 emissions are commensurate with the energy usage when comparing the results to published benchmarks. The impact of the renewable energy is:

- PV has a significant reduction in electricity use of 7.2%
- Thermal solar is more marginal with a 1% reduction in the heat delivered to the school

3.3.4 Potential Reductions

Applying these enhancements would reduce the electricity consumption by the order of 15%. This would see the DEC rating approach a B category.

4 Building Thermal Characteristics

The geometry of the 'pod' design has an impact on the thermal characteristics when compared to a more traditional massing of the building and using internal corridors for connection of spaces. The pods present greater external area for heat loss. However insulation standards went beyond the Building Regulations and were considered to compensate for the pod exposure in the design philosophy.

4.1.1 Fabric Performance

A thermal imaging survey was carried out on 9th January 2013 to coincide with air leakage tests. The full results are given in Appendix F. Examples from each of the clusters in Figure 13, Figure 14, and Figure 15 show the uniformity of the thermal response. Note that the ambient temperature over the test period ranged between 9°C to 11°C, internal conditions were being maintained at 20°C to 22°C.

Cluster 2 roof and walls show a uniform temperature which is close to the ambient dry bulb, internal conditions were being maintained at 18°C, see Figure 13. There appeared to be no acute thermal bridging with window and door frames being approximately 2 degC warmer than the main wall sections see Figure 14. This would be expected from the differences in U Value of the elements, see Figure 6 Insulation Standards of the Building Fabric.

Figure 13 Cluster 2 North-West facade

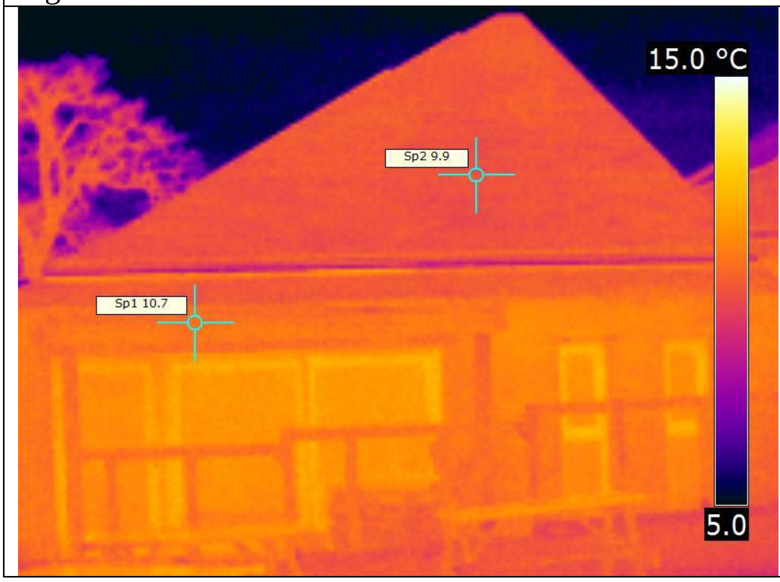
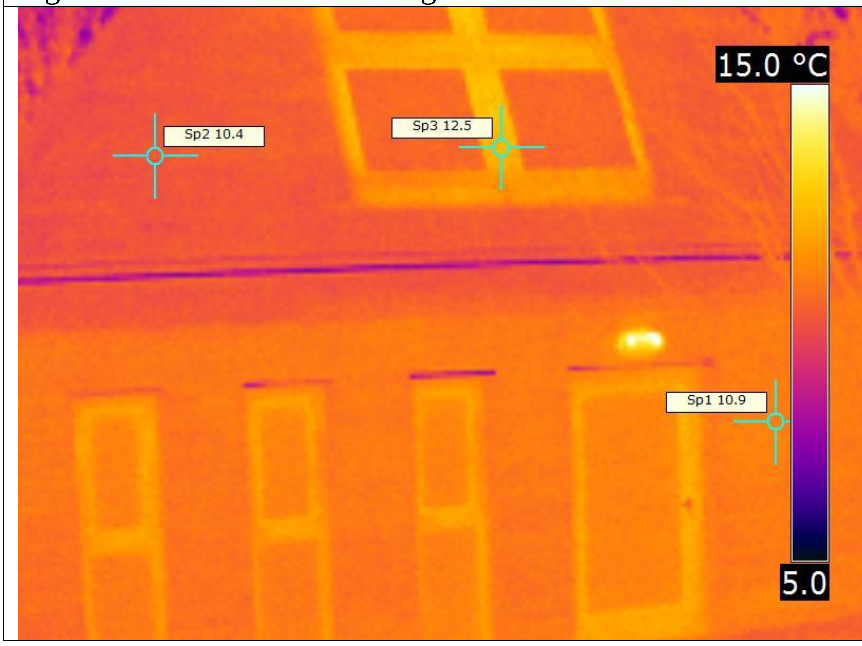


Figure 14 Cluster 3 North facing facade



Cluster 4 showed elevated temperatures on the façade but monitoring has showed that space temperatures were maintained by the space heating control at 2 degC higher in this Cluster.

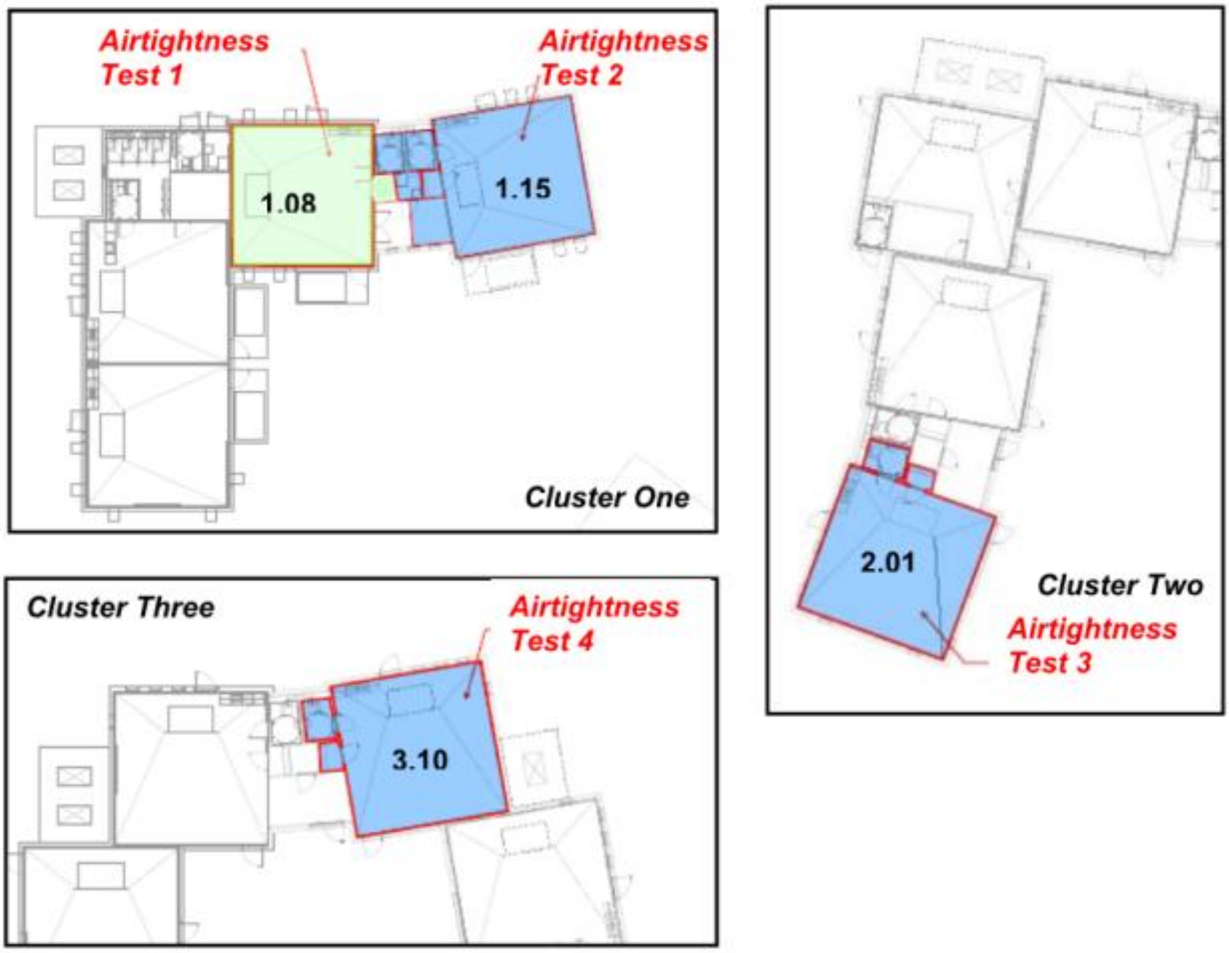
Figure 15 Cluster 4 North-West facade

4.1.2 Airtightness Testing

Airtightness testing of four sample classrooms was carried out on 7th January 2013 to determine the air permeability and identify leakage paths. A series of 50Pa depressurisation tests were carried out – a full record of the testing procedure and results is given in Appendix F.

The four classrooms tested are shown inFigure 16.

Figure 16 Sample of Classrooms Tested



The results from the tests are shown in Table 11. There is a significant variation in the results found with Cluster 1 spaces above the specification requirement for air permeability being < 5m^3/hr/m^2 @50Pa. Cluster 1 is evidently more 'leaky' than the spaces tested in Clusters 2 & 3 which did show a good level of air tightness and met the specification requirement.

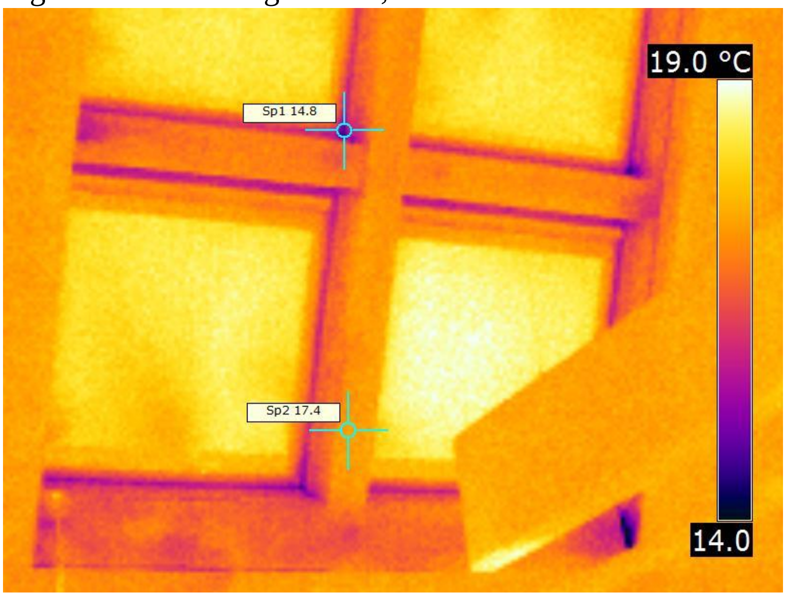
The factors that made Cluster 1 more 'leaky' than other spaces are not immediately evident as the construction detailing are the same. Cluster 1 spaces 1.08 and 1.10 do however have double doors to space 1.02 which had a visible gap between the door leafs through which a copious amount of air was flowing during the depressurisation tests.

Table 11 Air Tightness Test Results 9th Jan 2013

Parameter	Cluster1 - 1.08	Cluster1 - 1.15	Cluster 2 – 2.01	Cluster 3 – 3.10
Building Envelope m^2	250.5	310.7	260.7	260.7
Space Volume m^3	234.0	270.0	242.0	242.0
Air Permeability $m^3/hr/m^2$ @50Pa	6.1	7.0	4.3	3.6
Air changes per hr @ 50Pa	6.5	8.5	4.6	3.9

The depressuristaion tests were accompanied with thermal imaging to identify where leakage paths were in the construction these are given in Appendix E. The thermal images given in figures Figure 17, Figure 18, and Figure 20show likely air leakage paths at the junction of window frames, crackage around doors and service penetrations.

Figure 17 Air Leakage Test 2, Cluster 1



The principal air leakage paths in the Cluster 1 envelope were found at:

- Leakage around the roof-light frames
- Eaves joints
- Electrical conduits
- Vertical joint of sliding external door
- Supply ventilation duct penetrations
- Several locations in the rear of plant room CL1.11 particularly behind the mechanical ventilation heat exchangers
- Extract ductwork penetrating the roof in plantroom CL1.11
- Internal door frame to room CL 1.08

Figure 18 Air Leakage Test 1, Cluster 1- Supply air duct penetrations

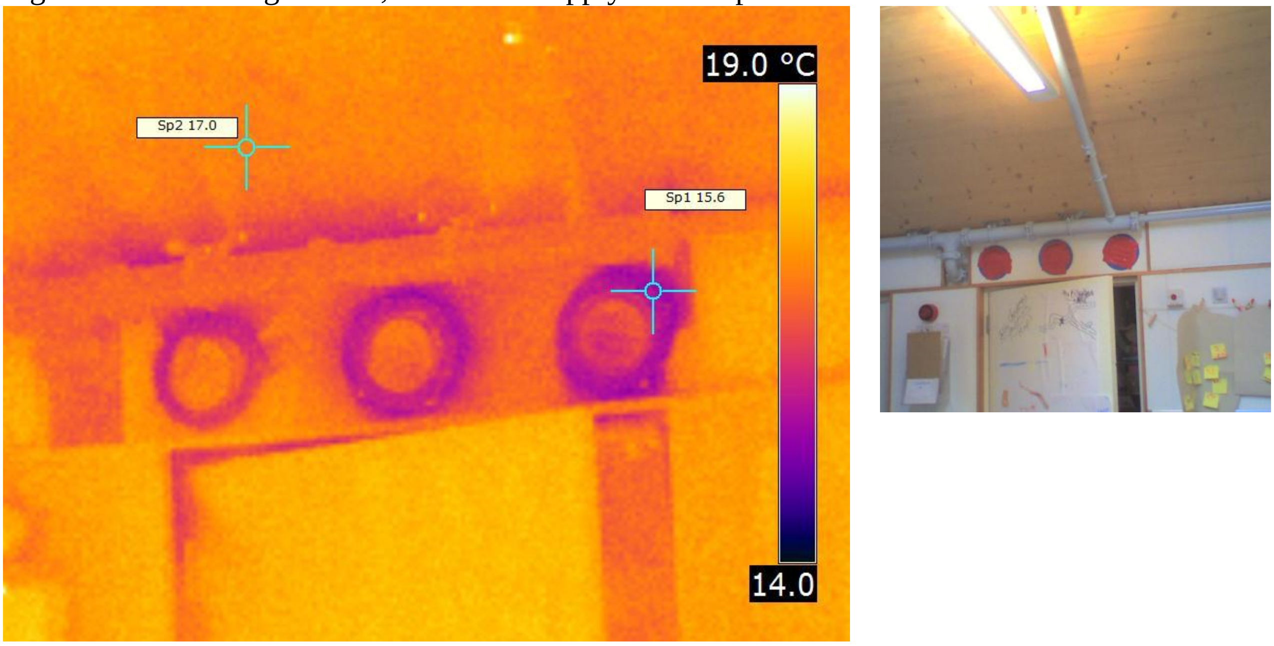


Figure 19 Air Leakage Test 2, Cluster 1- Mechanical Vent Heat Recovery Units

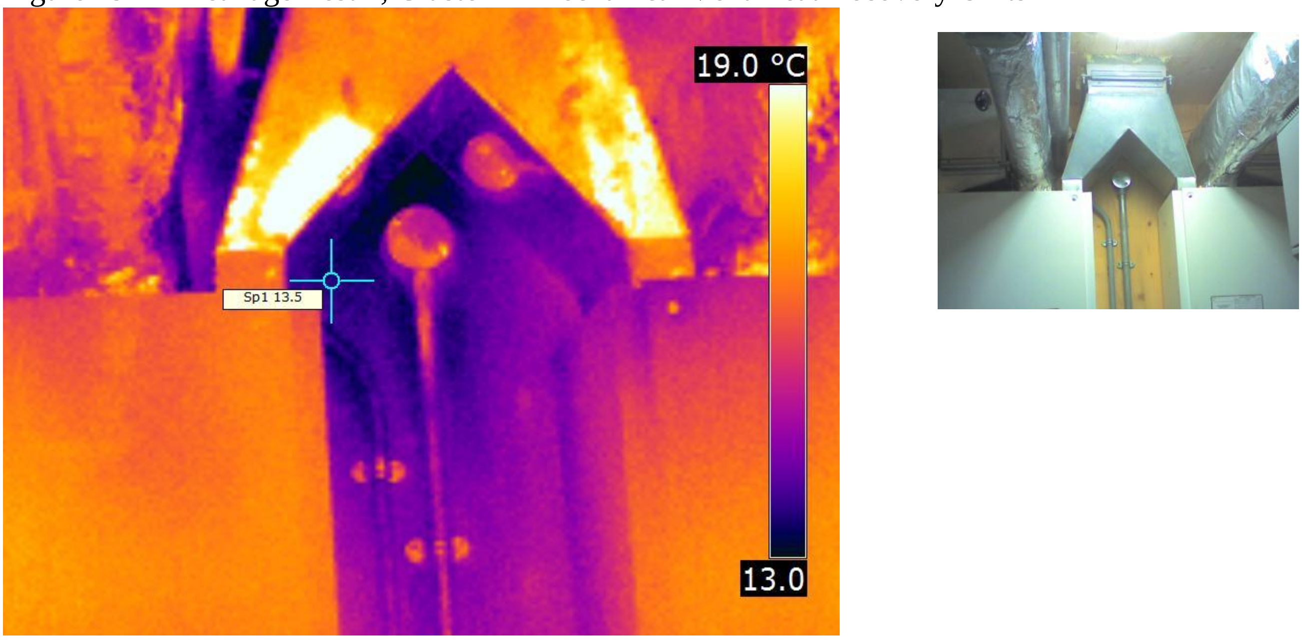


Figure 20 Air Leakage Test 2, Cluster 1

The air leakage paths found in Cluster 2 &3 were similar to those identified in Cluster 1 but less acute. However one major difference was the absence of the adjacent plantroom which was found to be a weakness in achieving low air permeability.

4.2 Key findings from Building Fabric Performance

Key findings from the thermo-graphic survey and air-tightness testing were:

- The building fabric showed a uniformity of temperature suggesting the insulation has been installed in a uniform manner with minimal cold bridging effects.
- As might be expected there were elevated temperatures on window and door frames but not to significant levels.
- The air tightness tests showed variable results with Cluster 2& 3 being better than the new build standard of 5 $m^3/hr/m^2$ @50Pa whilst Cluster 1exceeded this air permeability achieving levels between 6 to7 $m^3/hr/m^2$@50Pa.
- The effectiveness of the mechanical ventilation heat recovery system will be influenced by the air leakage rate which should ideally be less than 3 $m^3/hr/m^2$@50Pa. It certainly was the design teams expectation that the building construction should achieve less than
- Air leakage paths were more acute around roof lights, window and door frames under the depressurisation tests.
- Service penetrations for such things as electrical conduits and ventilation ducts were a weakness that contributed significantly to the air leakage through the envelope

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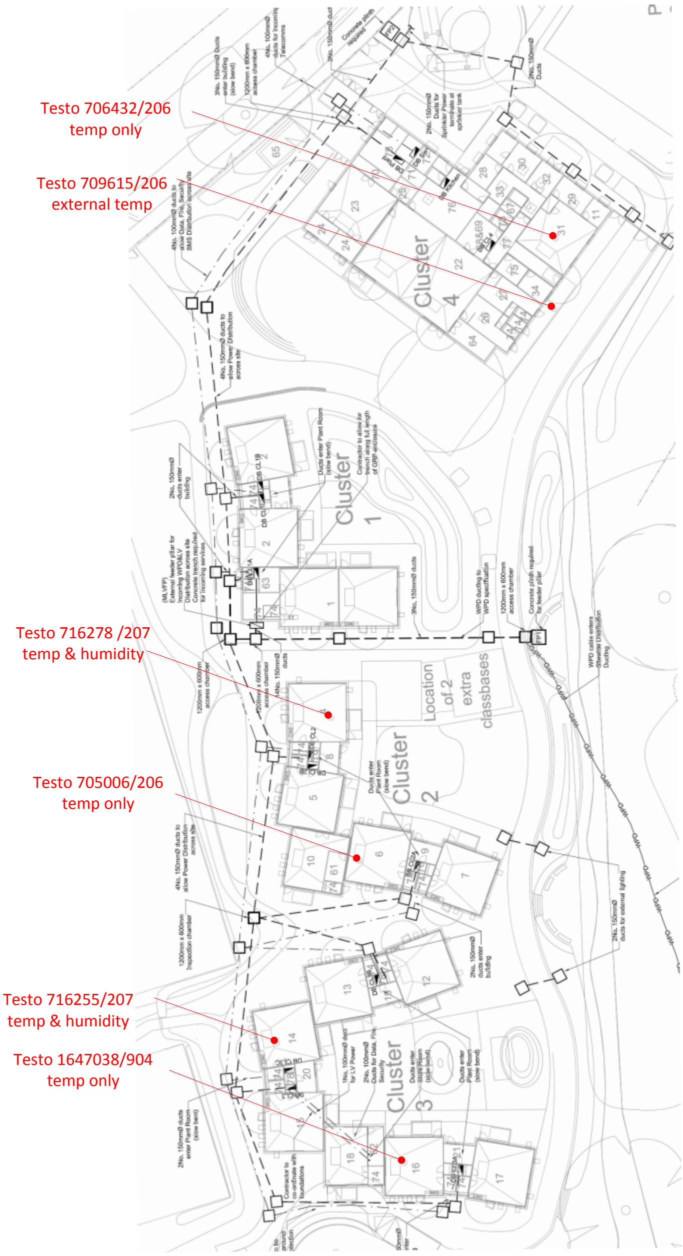
5 Environmental Control

5.1 Thermal Comfort of Spaces

The thermal environments in all 4 clusters were monitored using temperature and relative humidity data loggers, the stability of winter space heating control and summertime temperature distributions were assessed. The location of the temperature and relative humidity loggers during the two year monitoring period is detailed in Figure 21.

Figure 21 Location of Data Loggers



5.1.1 Cluster 2

The temperature in the classroom has been monitored to check the temperature met the requirements for classrooms as set out by the Buildings Bulletin 101 (BB101) and the Chartered Institute of Building Services Engineers (CIBSE). The results of the occupant survey discussed in Section 7 highlight issues raised by staff regarding air quality, stuffiness and overheating; however the data collected by the classroom data loggers shows that the classroom are well below the maximum temperature limits.

Figure 22 Cluster 2 Classroom Temperatures a winter time temperature profile in the Cluster 2 teaching space. The space is being controlled to set point of approximately 20°C. This trace illustrates the heat pumps are running continuously during this period. The increase in temperature seen principally on weekdays is the effect of occupancy gains.

Figure 22 Cluster 2 Classroom Temperatures

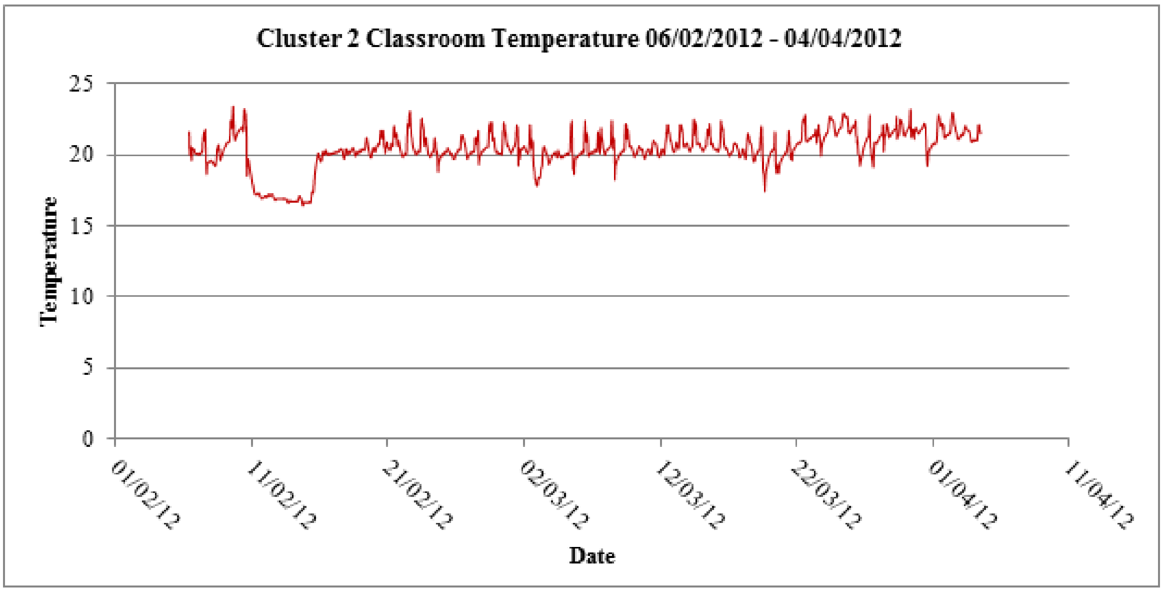


Figure 23 - Location of the Cluster 2 Temperature logger

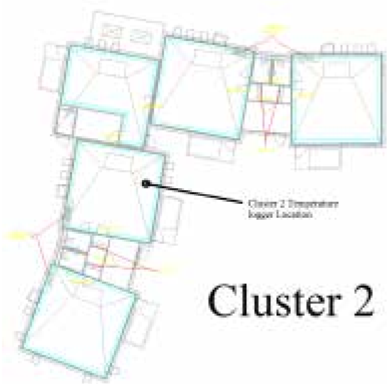


Figure 24 shows a summertime profile the peak temperatures occasionally swing above 25°C. The distribution of summertime temperatures is shown in Figure 25 Temperature Distributions during the period 06/06/2011 - 08/11/2011 mean band width is 20°C to 21°C with less than 4% of occupied hours in excess of 25°C.

Figure 24 Temperature Variation during the period 06/06/2011 - 08/11/2011

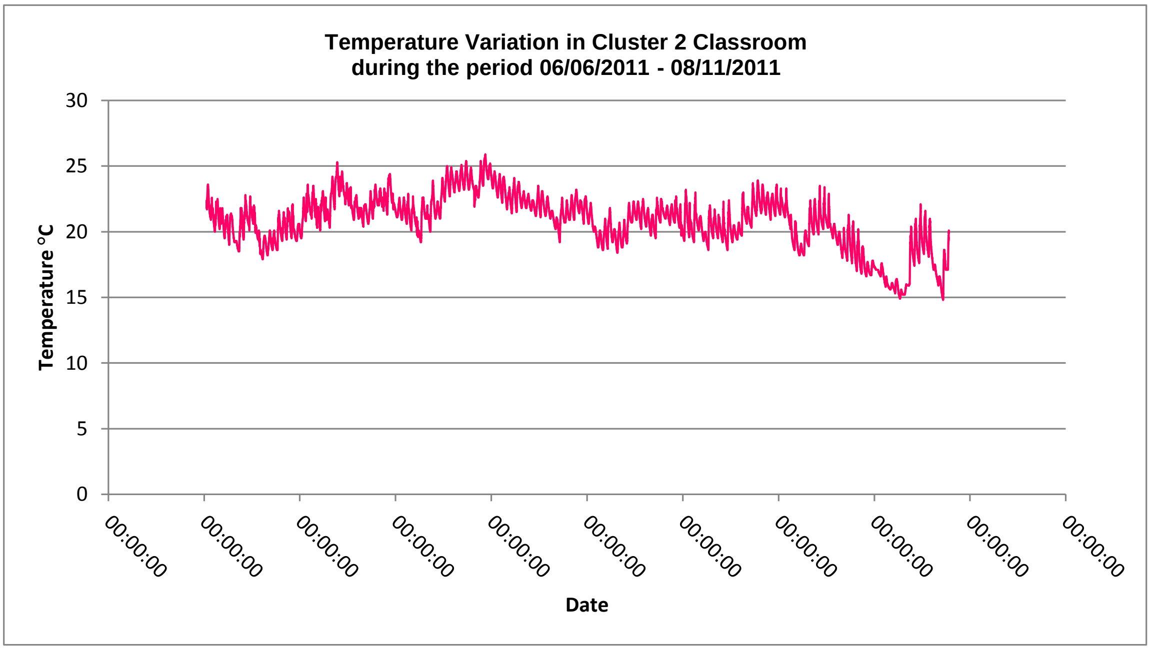


Figure 25 Temperature Distributions during the period 06/06/2011 - 08/11/2011

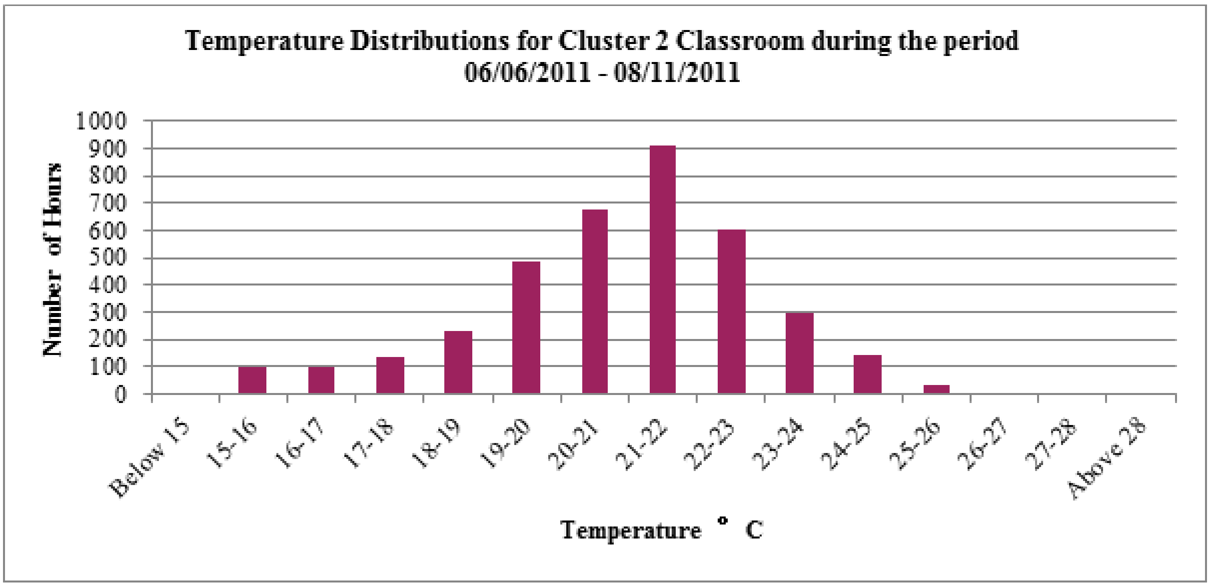
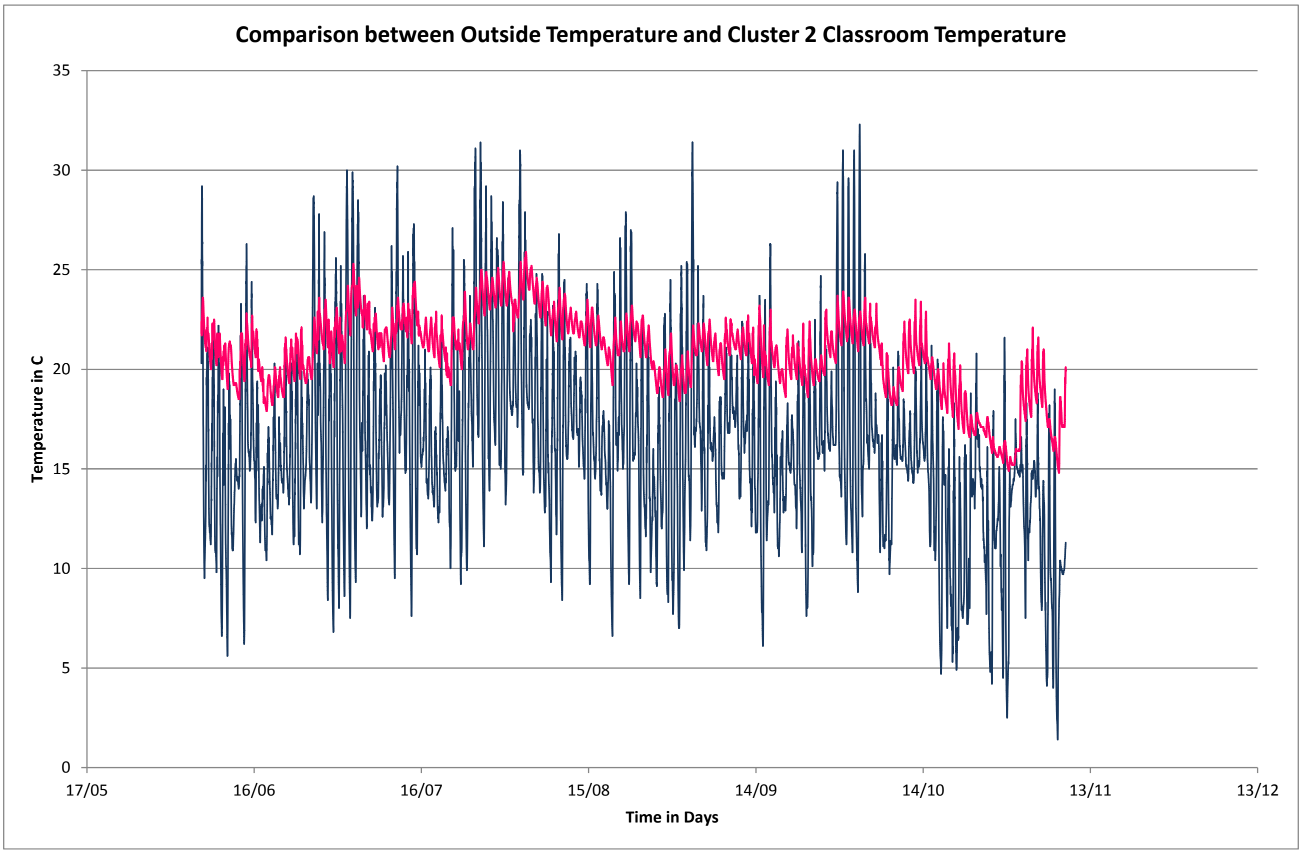


Figure 26 Classroom Temperature and Outside Temperature during the period 6/06/2011 - 08/11/2011



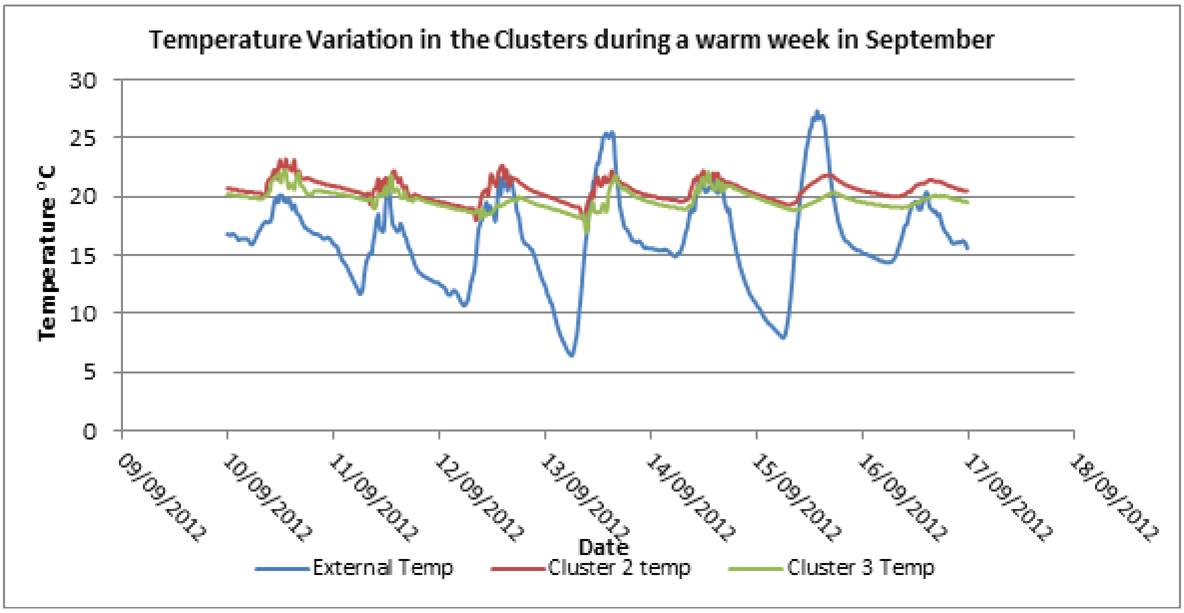
Note: low sun angle meant direct radiation was clipping outdoor air sensor in September

Figure 26 shows the correlation of classroom temperature and the outside temperature. The classroom temperature stays within acceptable bands whilst outside temperature shows wide diurnal changes. Note that ambient temperature was a recorded shade temperature there appears to be some radiant effects as the temperatures are elevated compared to ‘free field’ data.

Cluster 2 - Hot Week in September 2012

A hot week in September was analysed to show the classroom temperature during a particularly warm period, see Figure 27.

Figure 27 Temperature variation in the Cluster Classrooms during a warm week in September 2012

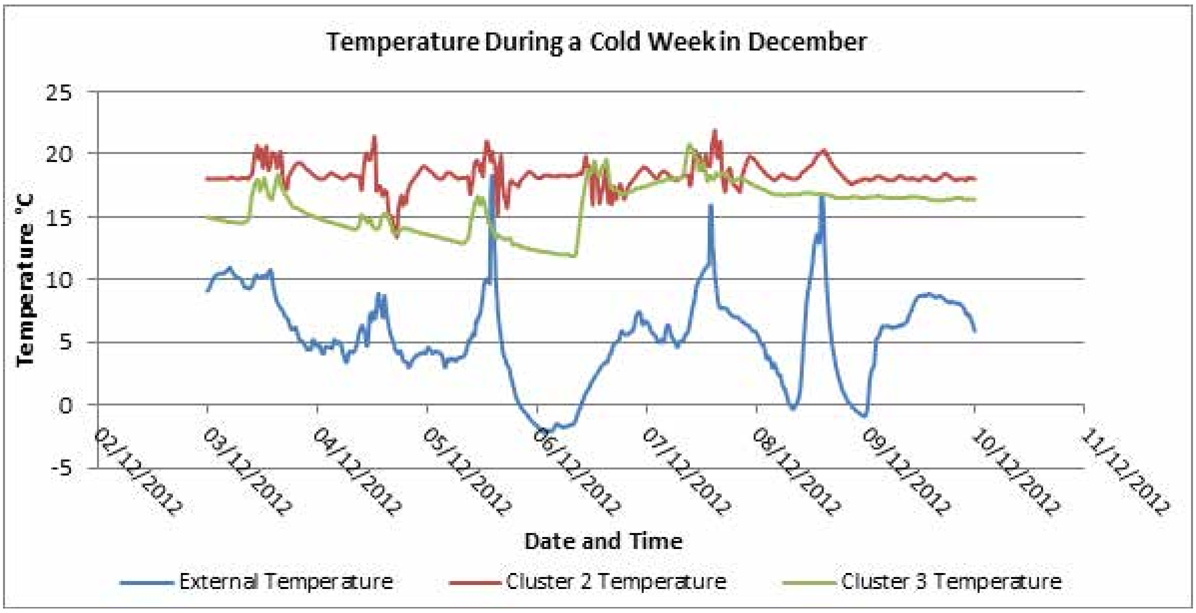


The graph shows that the clusters remain at a fairly constant temperature despite the external temperature fluctuations. On the 15th September the external temperature reached a peak of 26.7°C whereas the classrooms were 21.5°C. The external temperature reached a low of 7.3°C during this week but the classrooms remained at a fairly constant level and dropped only to 17.1°C.

Cluster 2 Cold Week in December 2012

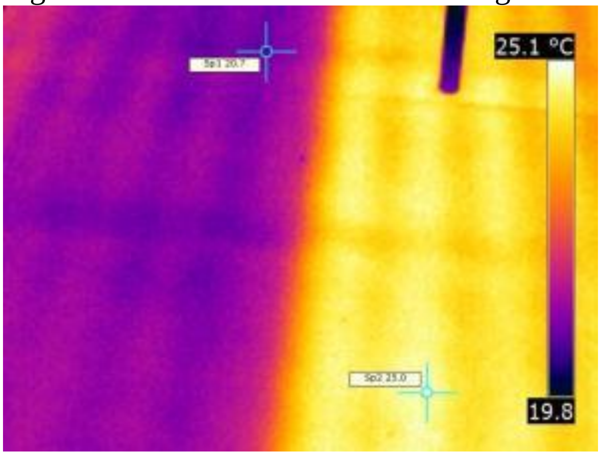
A cold week in December has also been analysed to show the classroom temperature response when the external temperature drops to below freezing, see Figure 28. This graph again shows that the clusters remain at a fairly constant temperature despite the fluctuations of the external temperature. Even when the outside temperature dips below freezing at 11pm on 6th December, the classrooms remain at 18.1°C and 12.3°C. Both classrooms reach 18°C or more for the take up of occupancy next morning.

Figure 28 Temperature variation in the Cluster Classrooms during a cold week in December



A point for concern was the results obtained on the underfloor heating which showed sections of the system at significantly lower temperatures than others, see Figure 29. This indicates that this section is not receiving sufficient water flow due to air lock, sediment or being valved off this should be checked in the next system service. There has been a history of air-locking in the floor coils and this this should be investigated.

Figure 29 Cluster 2 Underfloor Heating Detail



5.1.2 Cluster 3

Temperature loggers were placed in two classrooms in Cluster 3. Figure 30 shows the location of data logger 01647038. The monitored data showed the space temperature remained within reasonable limits for a naturally ventilated space. The temperature distribution shows a mean falling in the band 20°C-21°C. Summer time peaks show that 25°C is only exceeded for 23.4 hours and this mainly during the summer holiday period. Although there is no active control of RH it is at a level commensurate with summer moisture content levels but still within the comfort band.

Figure 30 Cluster 3 Temperature Logger Location

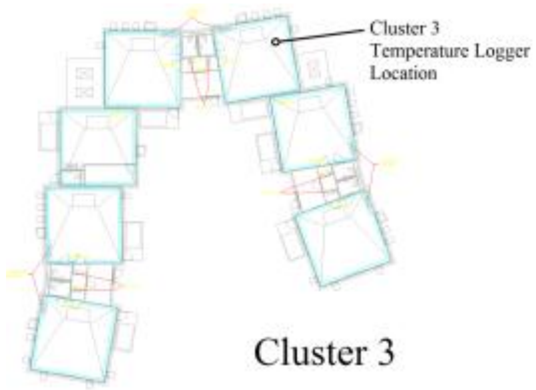


Figure 31 Cluster 3 Classroom Temperature Variations

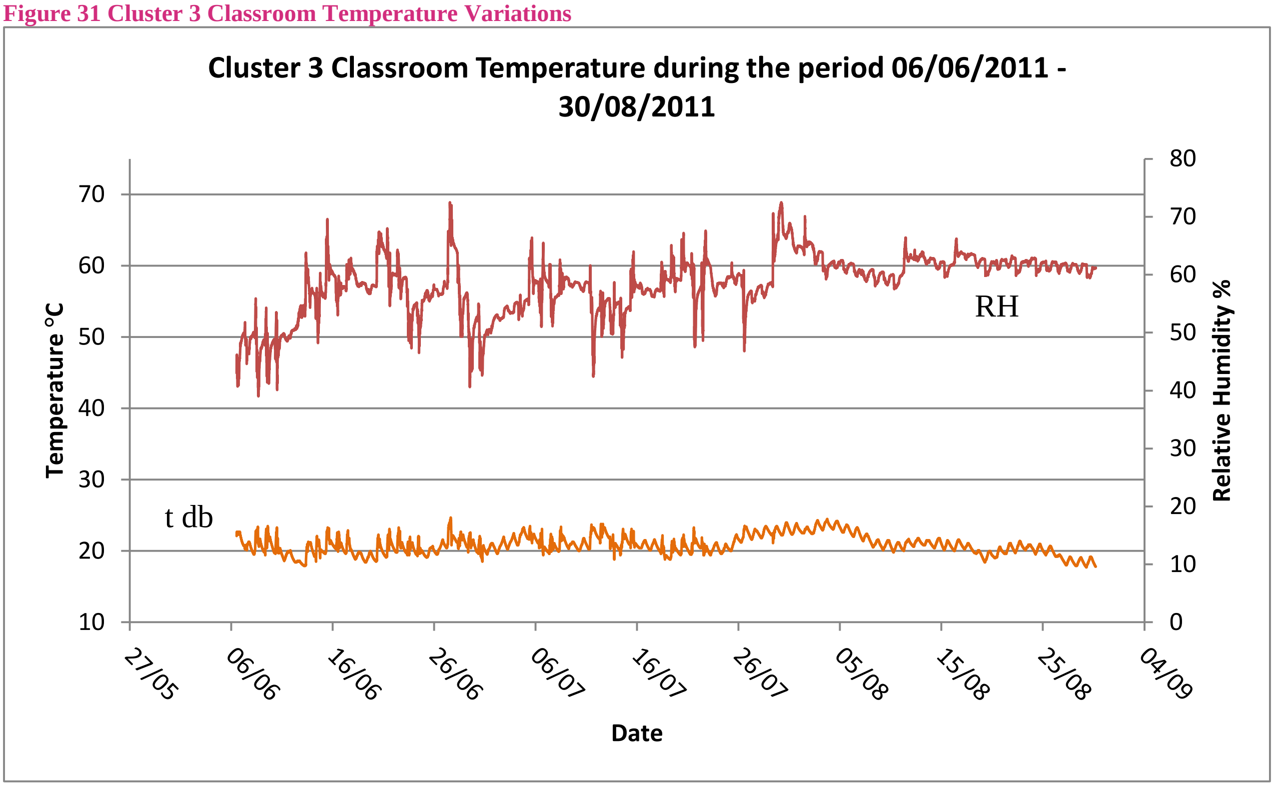


Figure 32 Temperature Distribution over the period 06/06/2011 - 08/11/2011

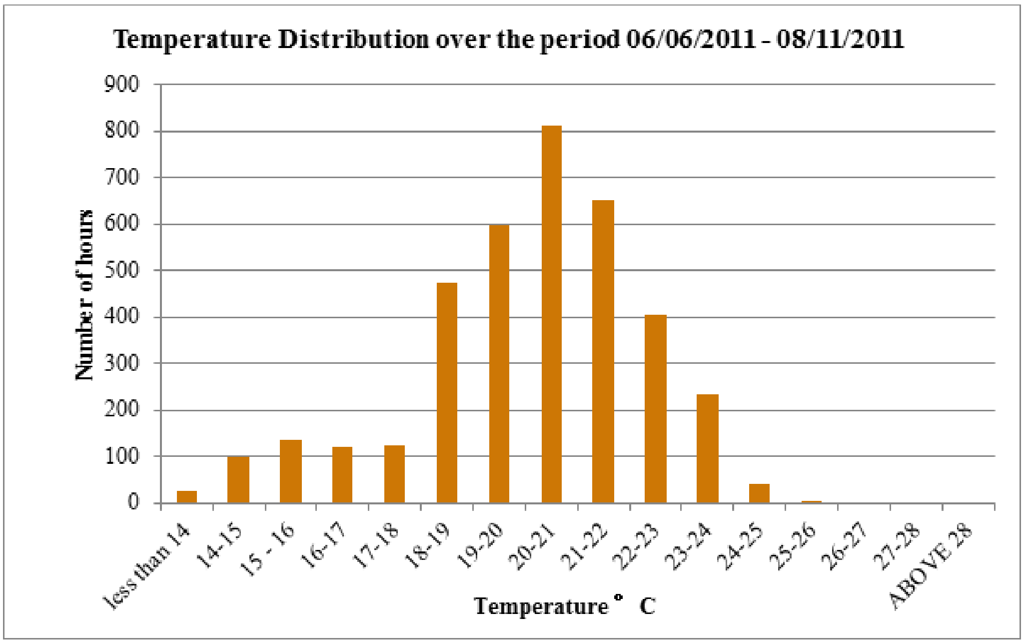
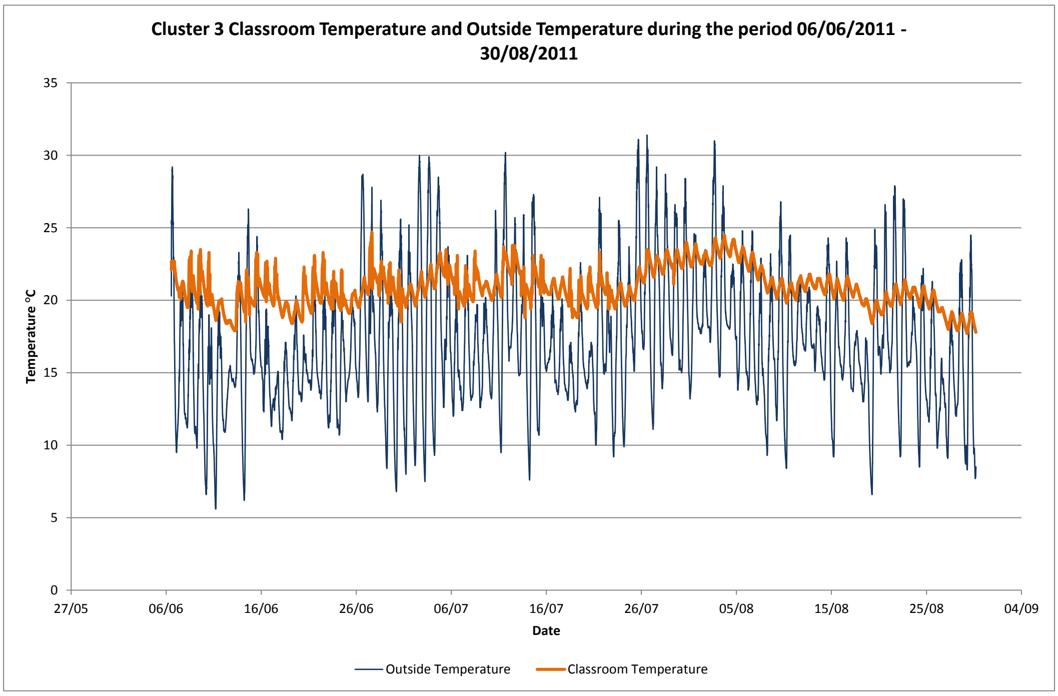


Figure 33 Classroom Temperature and Outside Temperature during the period 06/06/2011 - 30/08/2011



5.1.3 Staffroom

The staffroom is an area which has been highlighted by the occupant survey where spaces can be become uncomfortable during the summer months due to high temperatures. The following figures show the temperature distribution and variations during the period 06/06/2011 – 08/11/2011. The distribution shows a higher mean than the teaching clusters in 23°C -24°C band with 103 hours above 26°C.

Figure 34 Staffroom Temperature Variation during the period 06/06/2011 - 08/11/2011

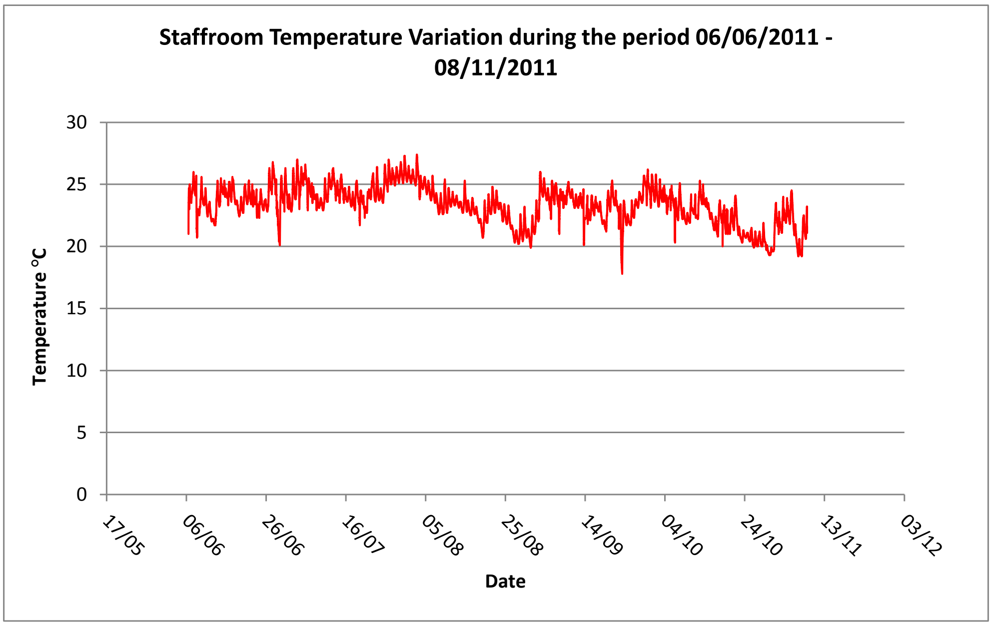
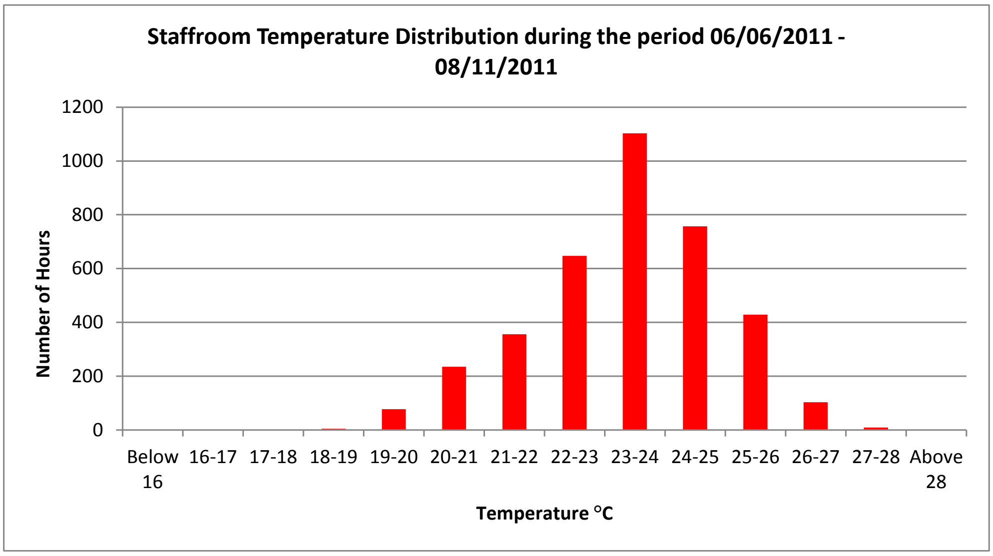


Figure 35 Staffroom Temperature Distribution during the period 06/06/2011 - 08/11/2011



The maximum temperature reached in the staffroom was 27.4°C on 02/08/2011 and the total number of hours which the temperature was above 27°C is 9.25hrs over this period.

Figure 36 Staffroom Temperature and Outside Temperature during the period 06/06/2011 - 08/11/2011

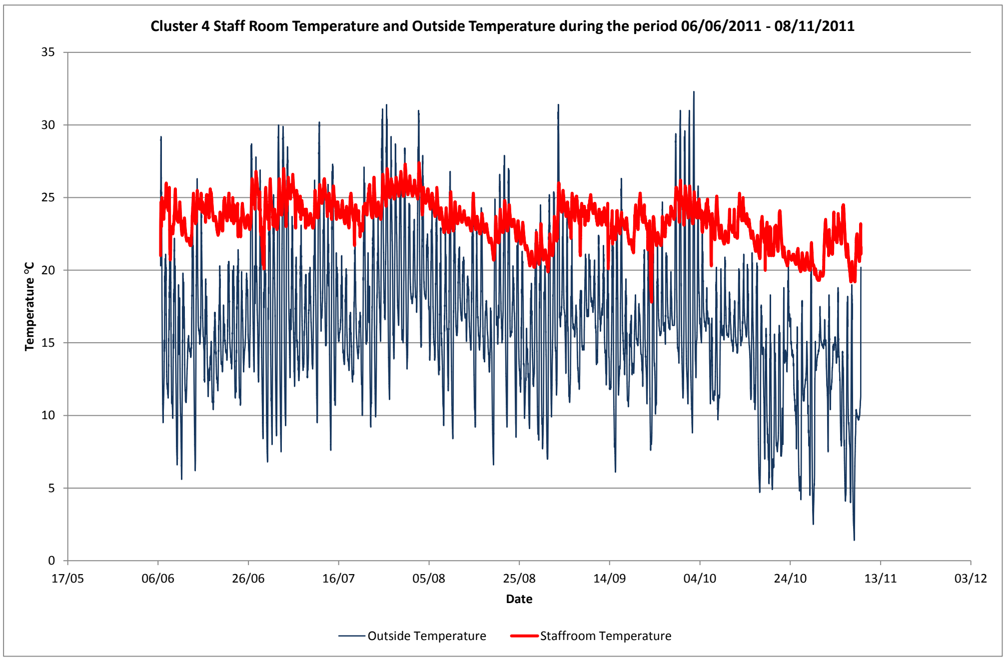
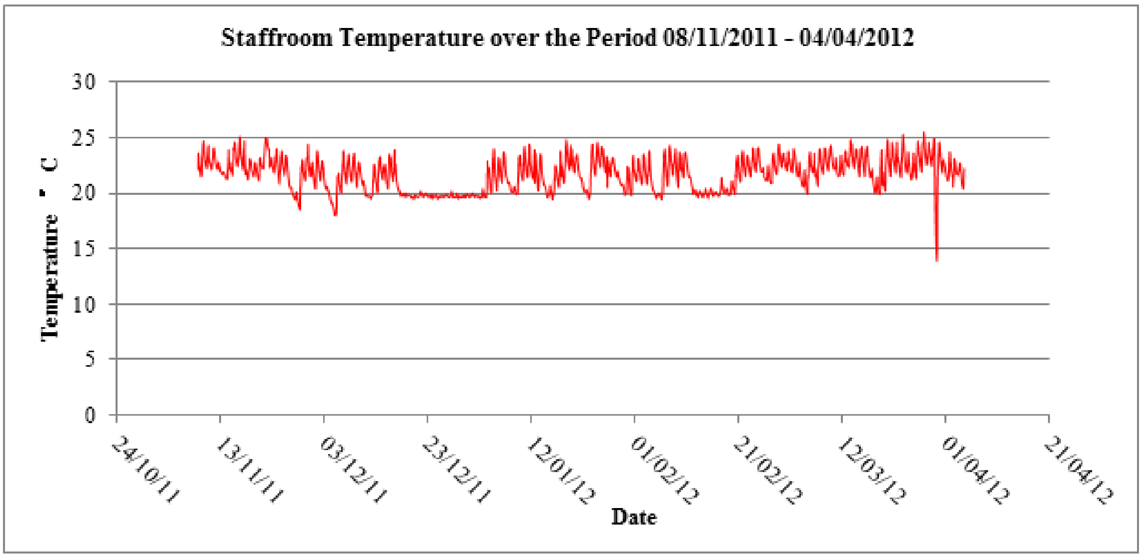


Figure 36 shows a comparison between the outside temperature and the staffroom temperature. The graph bears out the occupant observations that the space tends to operate at an elevated temperature when compare to the Teaching Clusters which persists into winter.

Figure 37shows the staffroom temperature during the period 08/11/2011 until 04/04/2012. The peak temperature reached is 25.2°C on 27/03/2012. The profile looks like the space is actively controlling to a set point of 23°C with an unoccupied set back temperature of 20°C. These settings are too high and contributing to the overheating. Conditions would be improved if this were to be reduced to say 21°C and the space heating plant set back temperature reduced to 17°C

Figure 37 Staffroom Temperatures over the period 08/11/2011 - 04/04/2012



The temperature in the staffroom during the period 07/01/2013 – 28/03/2013 is shown in Figure 38. The temperature distribution during this period is shown below in Figure 39. The staffroom temperature reaches a high of 26.1°C on the 30/01/2013 and a low of 18.6°C on the same day. The graph also compares the temperature of the staffroom to that of the external environment

Figure 38 Staffroom temperature between 07/01/2013 – 28/03/2013

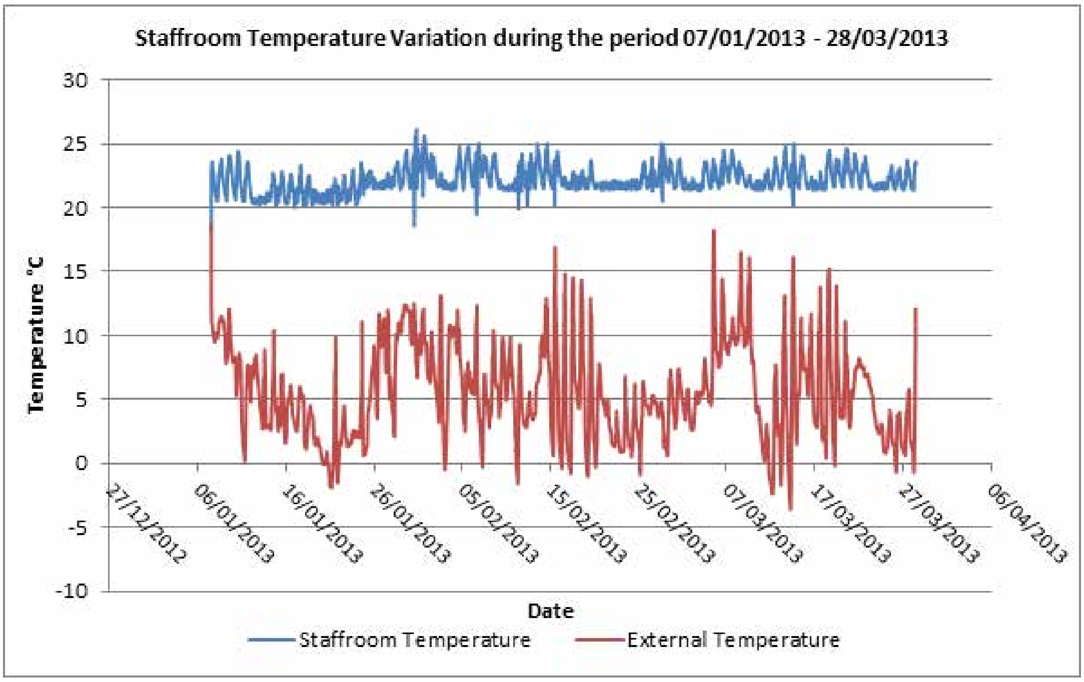
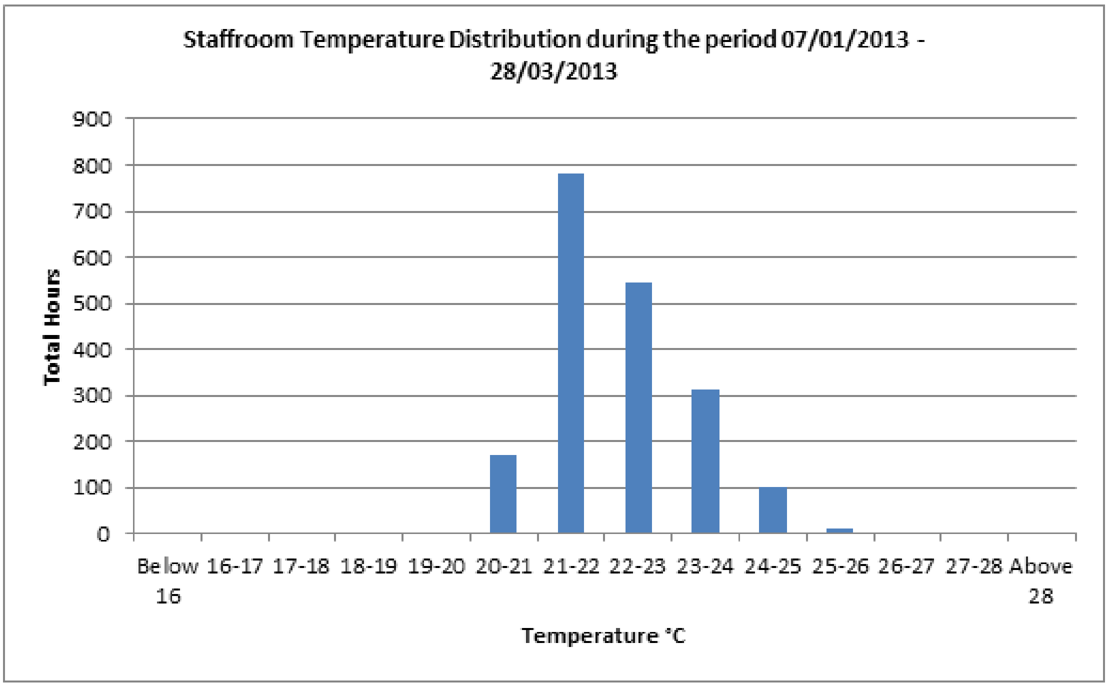


Figure 39 Staffroom temperature distribution between 07/01/2013 – 28/03/2013



5.1.4 Key Findings for Environmental Control

The results from the thermal environment monitoring show that:

- Summertime temperature distributions in teaching clusters were reasonable only exceeding 25°C for less than 4% of occupied hours – occupants response was equal to the national benchmark
- Wintertime temperature control was effective - occupants scored the space above the national benchmark in the occupancy survey

Cluster 4 was cited as a problem in terms of excessive temperature by the staff and this was borne out by the data which showed a shift in the distribution with mean lying at 23°C -24°C and 7% of occupied hours in excess of 26°C.

- Staff room temperature profiles indicate the plant is operating out of hours and at high set points – in winter this is around 23°C. The plant should be returned correctly scheduled pattern of operation with set points lowered to 21°C with unoccupied set back reduced to 17°C to give a fresher feel to the spaces.

The level of ventilation should also be reviewed in these spaces as the lack of rapid ventilation will be contributing to the overheating experienced. There is provision for rapid ventilation with openable windows but whether this can be introduced in winter months without the creation of discomfort due to cold draughts needs to be reviewed. In winter the control set-points adjustments should restore a better temperature distribution in the staff spaces.

Poor performance of the underfloor heating was noted in feedback from staff. The monitored data tends to show that comfort conditions were generally maintained so staff may have been referring to the occasional incidents where the floor coils air locked but worked satisfactorily after venting.

It was also observed from the monitoring that the heating systems were operating on a 24/7 basis. Naturally the scheduling of the heat pump should be reinstated with an appropriate set back condition of say 17°C. The teaching areas have a lightweight thermal response which means that temperature recovery would be achieved within one or two hours of preheat start.

The thermal imaging did reveal that there were certain sections of the underfloor loops that were ‘dead’ suggesting that there was no flow in these sections – manifolds should be checked to see if this is due to sediment, air locking or simply valved off.

6 Review of Building Services and Energy Systems

6.1 Heating System

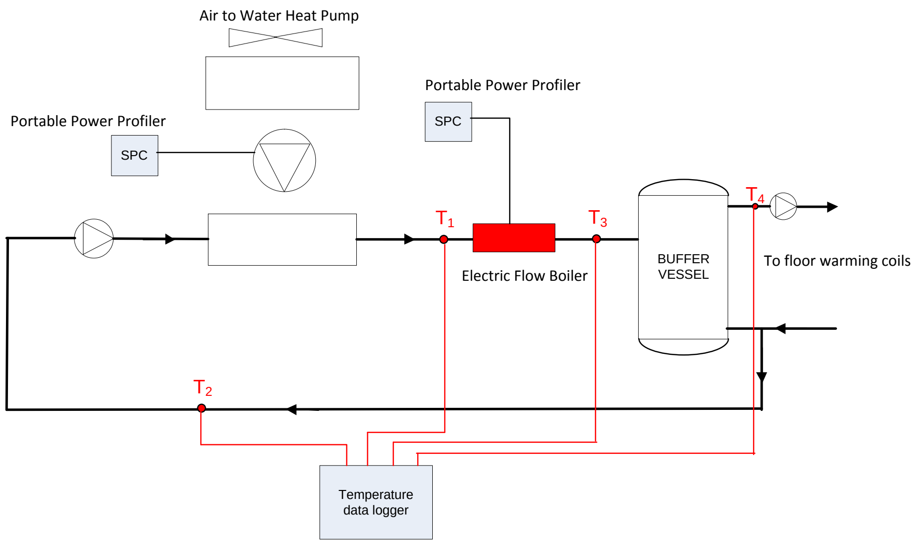
The space heating of the School is achieved with a number of systems. The teaching clusters are served with air to water heat pumps via under-floor heating. Cluster 4 has a more conventional gas fired boiler system serving low temperature hot water systems delivering heat to under-floor heating radiators and air handling units. The principal systems are described in this section, more detail can be found in Appendix A.

6.1.1 Clusters 1, 2 & 3 Heat Pump System

In Clusters 1, 2 & 3, underfloor heating provides the primary heat for the teaching and ancillary spaces. The heating is supplied via a Nibe Air Source Heat Pump each with 14kW nominal heating capacity located in an outside plant 'pen' to the rear of the Clusters. Heat Pumps were chosen as a low carbon alternative to a gas heating system to reduce the emissions from the site and lower its dependence on conventional fossil fuel. Heat pumps are considered a low carbon source of heating and are used in conjunction with a solar hot water system at the school to produce a low carbon heating strategy.

Clusters 1, 2 and 3 each have a primary circuit with an inline 200litre buffer tank complete with a 3kW immersion heater and expansion vessel, see Figure 40 Heat Pump Schematic for Clusters 1, 2 and 3. This figure also shows the monitoring arrangement where Type T thermocouples were recording the temperature profile across the system and were logged on a Testo 4 channel data logger. The power consumption of the heat pump and the supplementary electric flow boiler were recorded on a portable power profiler. Heat quantities have been determined based on constant primary water flow rate.

Figure 40 Heat Pump Schematic for Clusters 1, 2 and 3



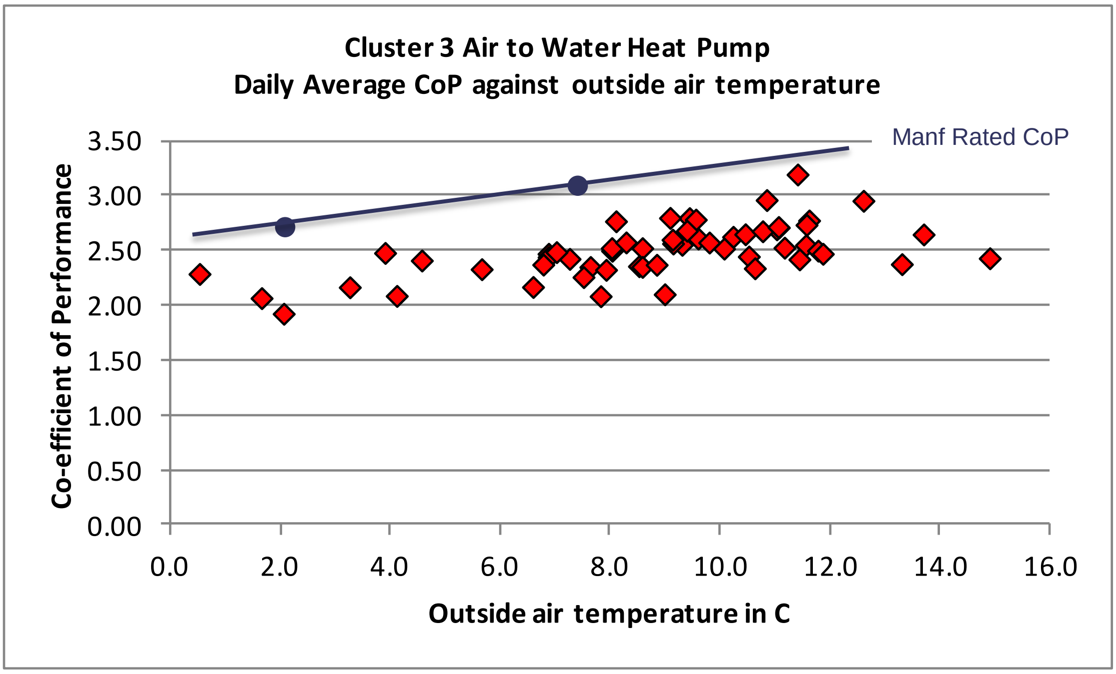
6.1.2 Heat Pump Performance

A correlation of heat pump co-efficient of performance (COP) against outside air temperature is given in Figure 41. This is a 'flat' characteristic tending to reduce in lower ambient as the compressor pressure 'lift' increases in lower ambient temperatures. The power demand profile is shown in

Figure 44. This shows a cyclic operation of the compressor during the period 8/11/11 to 2/2/12.

The COP is typical for an air source machine achieving values above 2.0 for cold weather operation (in ambient temperatures less than 5°C. The machines are running marginally lower than manufacturer's rating, this is not uncommon and is likely to be caused by the fine tuning of the machines controls, refrigerant charge, defrost effects in cold weather. Warm weather CoPs drop as the Cluster heating demand drops and the heat pumps begin cycle with greater frequency.

Figure 41 Cluster 3 AWHP - Correlation of COP against Outside Air Temperature



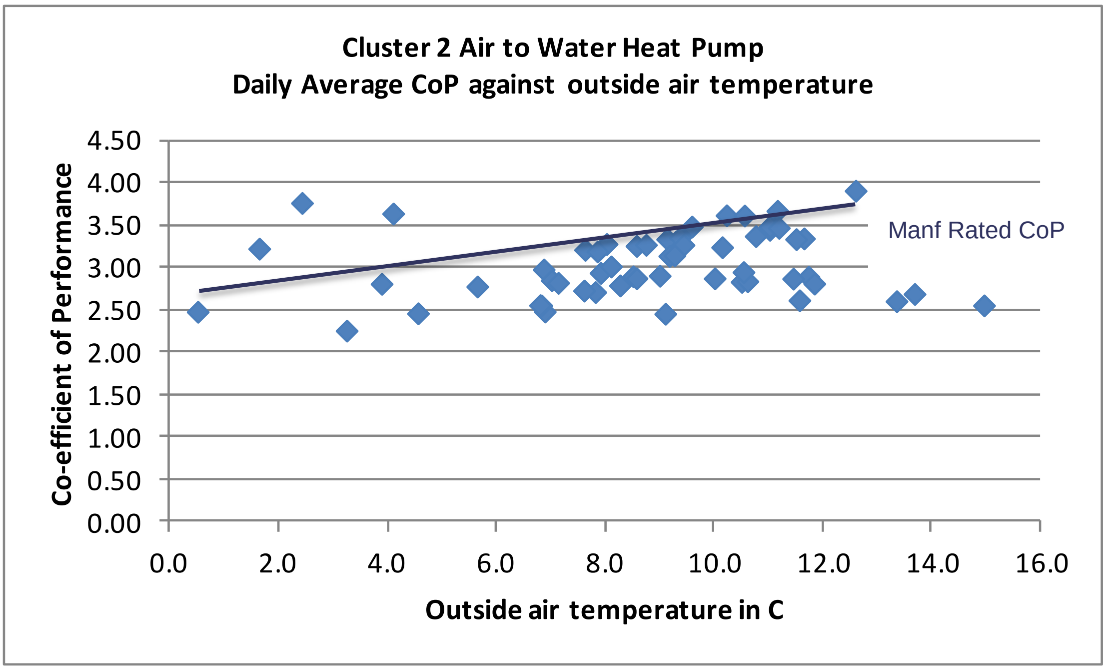
The manufacturer's CoP data for the Nibe Fighter 2025 -14 is given in Table 12.

Table 12 Heat Pump Manufacturer's CoP data – Nibe Fighter 2025-14

Ambient temp °C	Heat pump flow temp °C	Heat output kW	Electric Power kW	CoP
-7	50	9.5	4.2	2.26
2	50	12.2	4.5	2.71
7	50	13.9	4.6	3.02

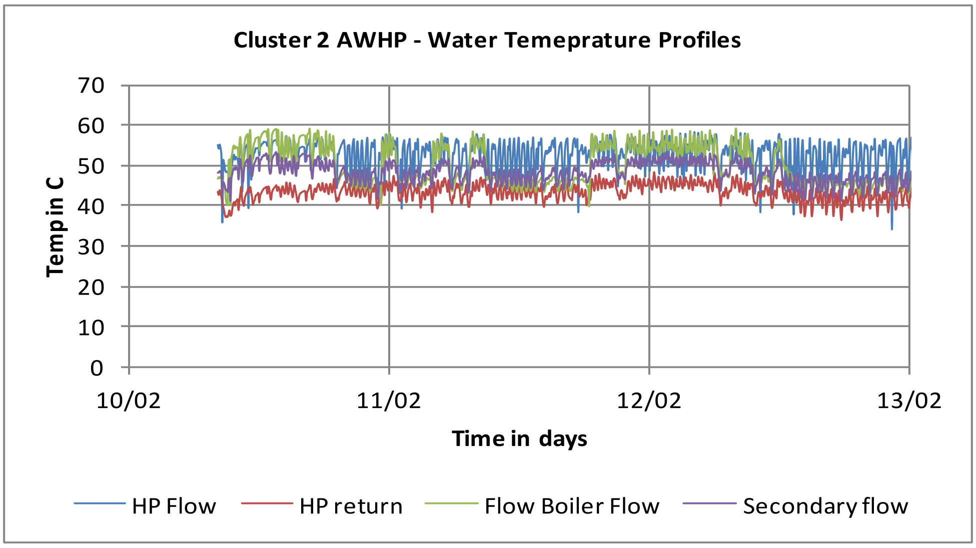
The heat pump characteristic for a Cluster 2 heat pump is shown in Figure 42 Cluster 2 AWHP Correlation of COP against Outside Air Temperature There are some elevated CoPs in cold weather that buck this trend and are more likely to be data anomalies than real effects.

Figure 42 Cluster 2 AWHP Correlation of COP against Outside Air Temperature



The heat pump water temperatures in Figure 43 show that the heat pump is running continuously which was noted on the thermal performance analysis which is wasteful. The installed SMO 10 heat pump controller has the facility for scheduling the machines and providing set-back control but had been not implemented. The school has been advised of this and will organise for the controller to be configured correctly. The machines are providing water to the heating circuits at 50°C with an approximate temperature difference of 5°C between flow and return. The electric flow boiler is only called upon occasionally to elevate the temperature to 58°C.

Figure 43 Cluster 2 Detail AWHP Water Temperature Profiles



The continuous operation of the heat pumps is reflected in

Figure 44 and Figure 45 .

The level of demand is consistent with manufacturer's rated absorbed power of approximately 4kW. The profile showing 90minutes –on 90 minutes off pattern being dictated by the flow water temperature control rather than on the space temperature thermostat

Figure 44 Heat Pump Power Demand Profile

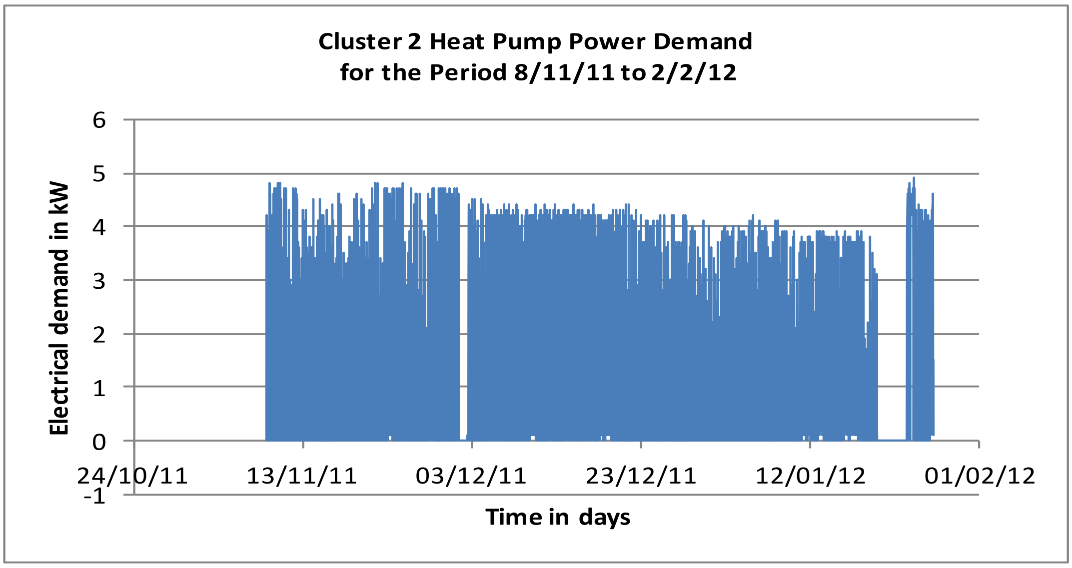
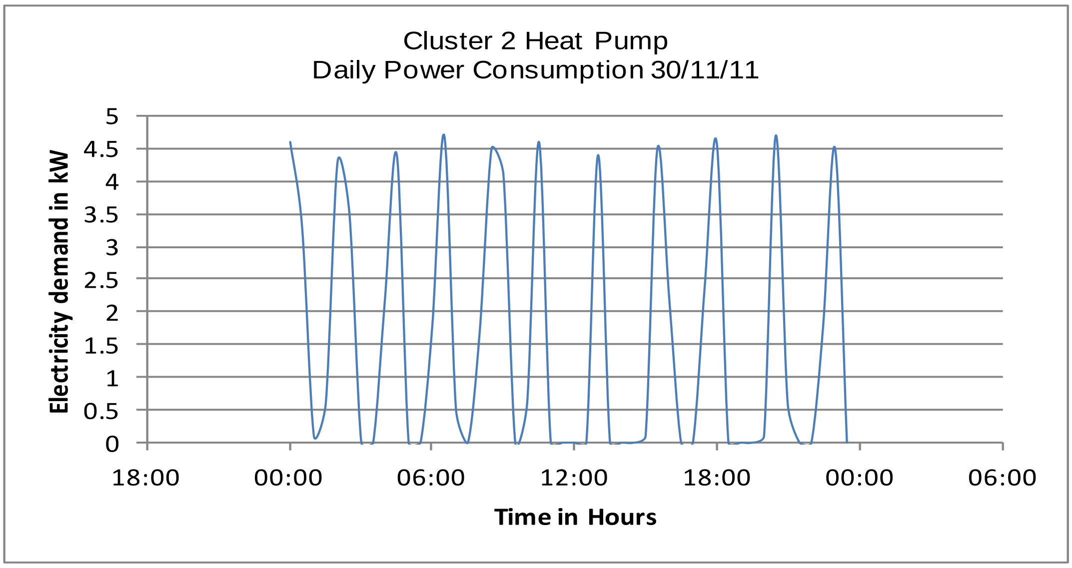


Figure 45 Heat Pump Daily Electricity Demand Profile



6.1.3 Operation of the Flow Boilers

The electric flow boilers provide supplementary heating for the air source heat pumps. The consumption of the electric flow boiler is low as can be seen from the power profile in Figure 46. The flow boiler power profiles show that during the first measured period, there was only 1 hour of loading on 26/01/2012. During the second measured period, there is mostly zero use with a few periods of intermittent loading; for example loading for 2-3hours every 2-3 days. During the period 8-12 February the operation is more frequent as the flow boiler compensates for lower heat pump outputs during the periods of low ambient temperatures. Data from the other teaching clusters reflect this pattern of operation, see Appendix B.

From this data the supplementary heat from the flow boiler represents 6% of the total electricity consumed by the heat pump plant serving the teaching clusters.

Figure 46 Cluster 2 Flow Boiler Power Demand for the period 26/01/2012 - 04/04/2012

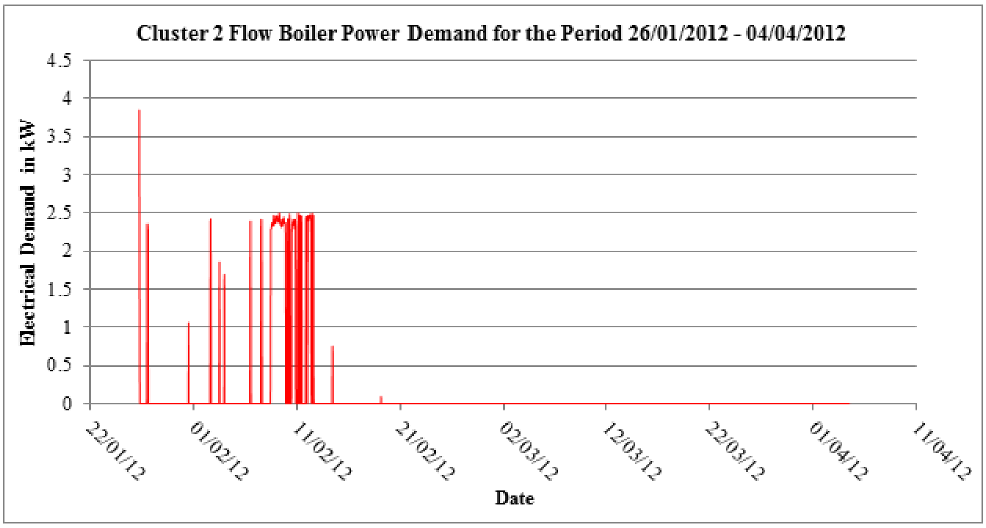
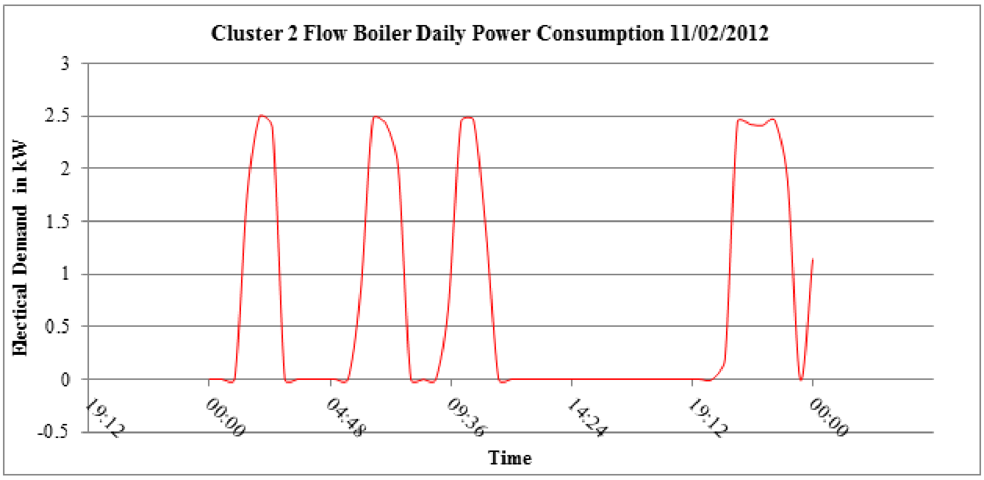


Figure 47 Cluster 2 Flow Boiler Daily Power Consumption 11/02/2012



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6.1.1 Key findings on the operation of the Heat Pump Plant

There are a number of ares where the school could make considerable improvements performance of the heat pumps

- The heat pumps are not time switched they run continuously through the winter period this leads to excessive electricity consumption.
- Circulation pumps serving the heat pump circuits are run for extended hours which results in wasted electrcity.
- The heat pumps have local controllers (SMO10 Controllers) that can be configured to schedule the operation of the machines and provide set –back control. This will reduce the run hours save energy and wear and tear on the machines.
- The heat pumps should also be scheduled against outside air so that in milder condtions condensing pressures can be reduced so improving the seasonal CoP reducing energy consumption.
- The control of the electric flow boilers looks effective only operating in the coldest weather when output from the heat pump will be at its lowest and the machine's under-going periodic de-frosting to keep the outdoor coil free from ice build up.

6.2 Classroom Mechanical Ventilation Systems

3.2.1. Clusters 1, 2 & 3 Mixed Mode Ventilation

Heat recovery units housing two fans and a plate heat exchanger are located in each cluster plant room. During winter operation, fresh air is ducted from the roof via to the exhaust heat recover recuperator , then delivered to the teaching spaces by three manually operated jet diffusers, see Figure 48.

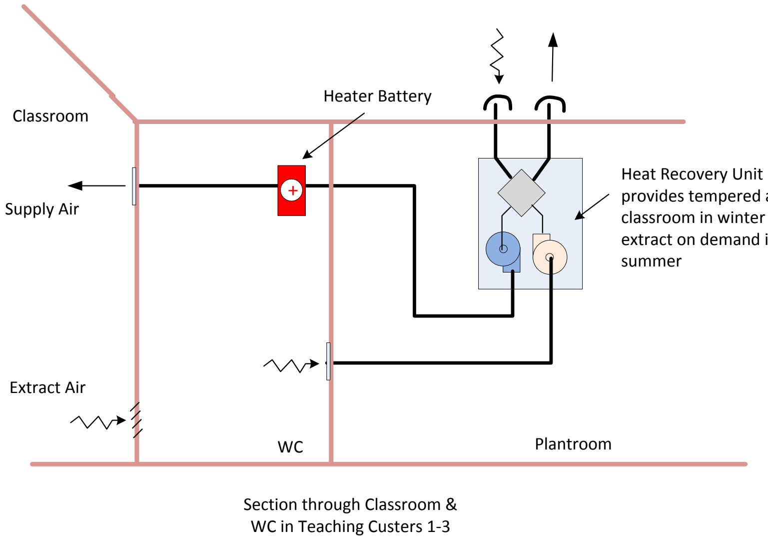
Return air passes from the teaching space into the toilet via door transfer grilles before being extracted from the toilet via an extract grille mounted at high level within the toilet. The air then passes through the heat exchanger before being exhausted above the roof. During the winter the clusters therefore operate a mechanical ventilation strategy. The system is enabled by a time schedule control to operate only during the occupied period and when the ambient temperature is below 8°C.

During summer operation, ventilation in the teaching spaces is achieved by openable windows. At this time when the heat recovery system is not active, mechanical ventilation of the toilet areas is achieved by a local wall mounted extract fans.

The toilet extract fan is operated via a PIR detector complete with a 20 minute 'run-on' timer. During winter operation this fan is not active.

Cluster 1 teaching space adjacent to the group toilet area operates the heat recovery unit throughout the occupied year in order to maintain the required toilet ventilation; The ventilation was time controlled so that fresh air is supplied during the occupied hours of the school.

Figure 48 Typical Layout and Simplified Schematic of the Classroom Ventilation System

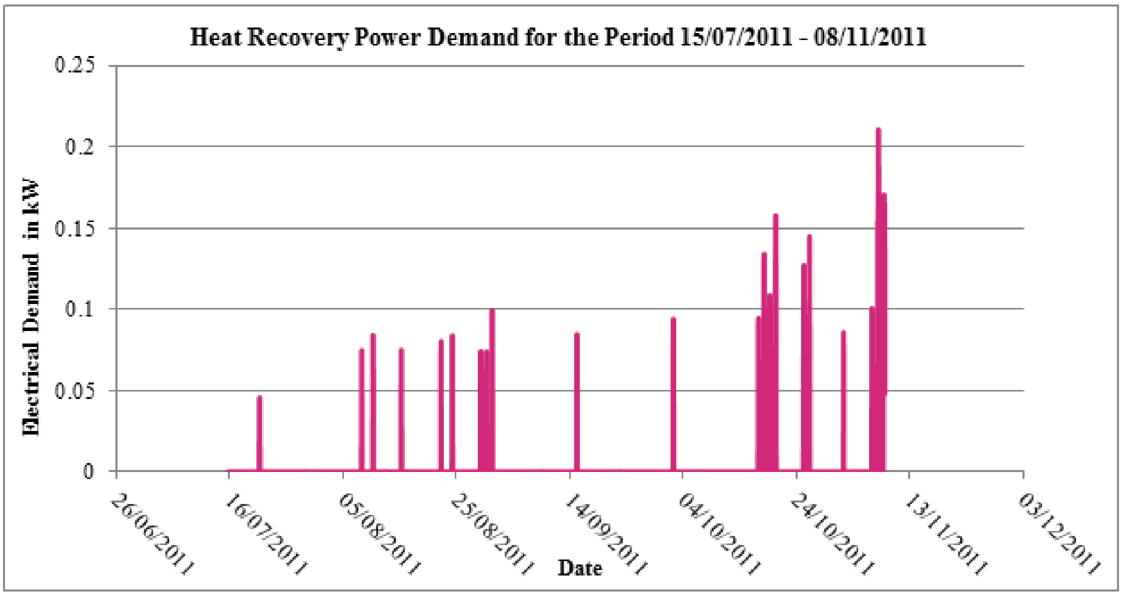


3.2.1. Performance of the Ventilation System

The power profile for the heat recovery unit is shown in Figure 49. The run-time is extended with the onset of colder weather with greater frequency of days when outside air temperature was below 8°C. The effectiveness of the ventilation was examined in March 2013 with detailed site tests.

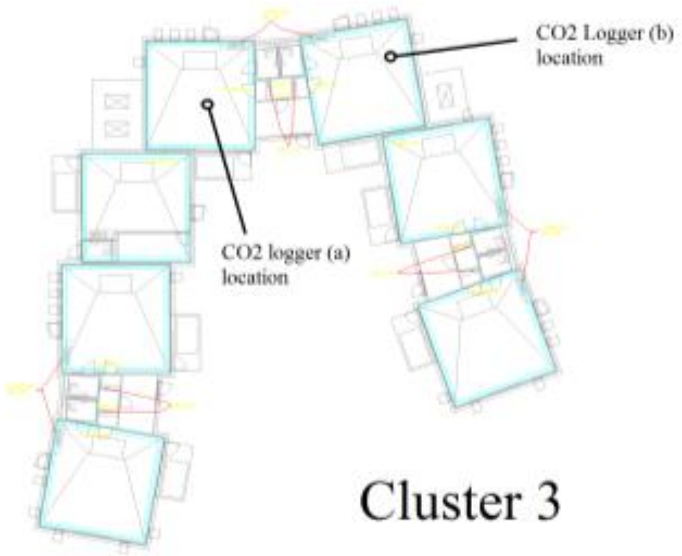
The graph in Figure 49 shows the occasional loading of the mechanical vent system for approximately 1hour in the mornings for a few days during the week.. Surprisingly this is occurring in the summer period when the system should have been scheduled off as there was no-one using the teaching clusters. The run-time is extended with the onset of colder weather with greater frequency of days when outside air temperature was below 8°C. The effectiveness of the ventilation was examined in March 2013 with detailed site tests.

Figure 49 Heat Recovery Power Demand for the Period 15/07/2011 - 08/11/2011



To examine the effectiveness of the mechanical ventilation system CO_2 sensors were installed in two classrooms in Cluster 3 so that the efficiency of the mechanical ventilation heat recovery units can be analysed, the locations of the loggers are shown below in Figure 50.

Figure 50 CO_2 Logger Locations in Cluster 3



The graph shows the CO_2 level in the classroom and the mechanical ventilation unit energy consumption indicating when the unit was operating. The graph in Figure 51shows that the CO_2 levels in the classroom reach elevated levels and peaks at 2009ppm at 13:40 on 15/02/2013. When the CO_2 level reaches this level, the stuffiness in the room appears to encourage the teacher to use the openable windows to bring conditions back to more acceptable perceived air quality levels – this equates to a CO_2 of around 1000ppm. The excursions to higher CO_2 levels are always short-term.

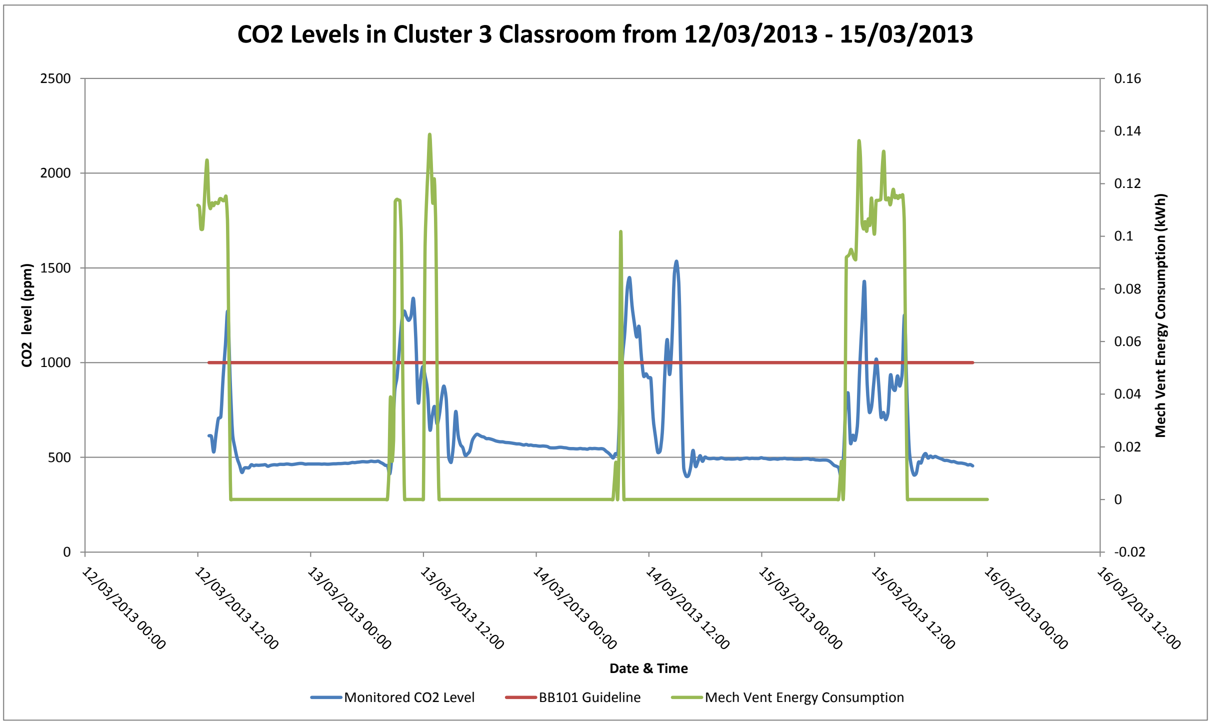
Figure 51 shows the mechanical heat recovery cycling on and off over a period of three days in March. The mechanical ventilation heat recovery is controlled by the external temperature and a time clock. Therefore if the outside temperature drops below 8°C and it is during the schools operating hours, the mechanical ventilation will turn on. The strategy behind this is that the main control for the CO_2 levels is the teachers opening the windows when the room becomes stuffy; this should then bring CO_2 levels down to produce a more comfortable environment. By implementing a natural ventilation strategy as much as possible, both energy consumption and carbon emissions from the mechanical ventilation systems are reduced.

The design intent is based upon the premise that at when outside air is less than 8°C then the mechanical ventilation system will control indoor air quality. When the outside air temperature is above this then ventilation will be achieved natural ventilation - teaching staff operating the roof light and then windows to introduce greater quantities of outside air. This can be seen in the classroom profiles

The BB101 guidelines state that the CO_2 levels *"When measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of* *carbon dioxide should not exceed 1500 parts per million (ppm)".* In addition, "*at any occupied time the occupants should be able to lower the concentration of CO_2 to 1000ppm*".

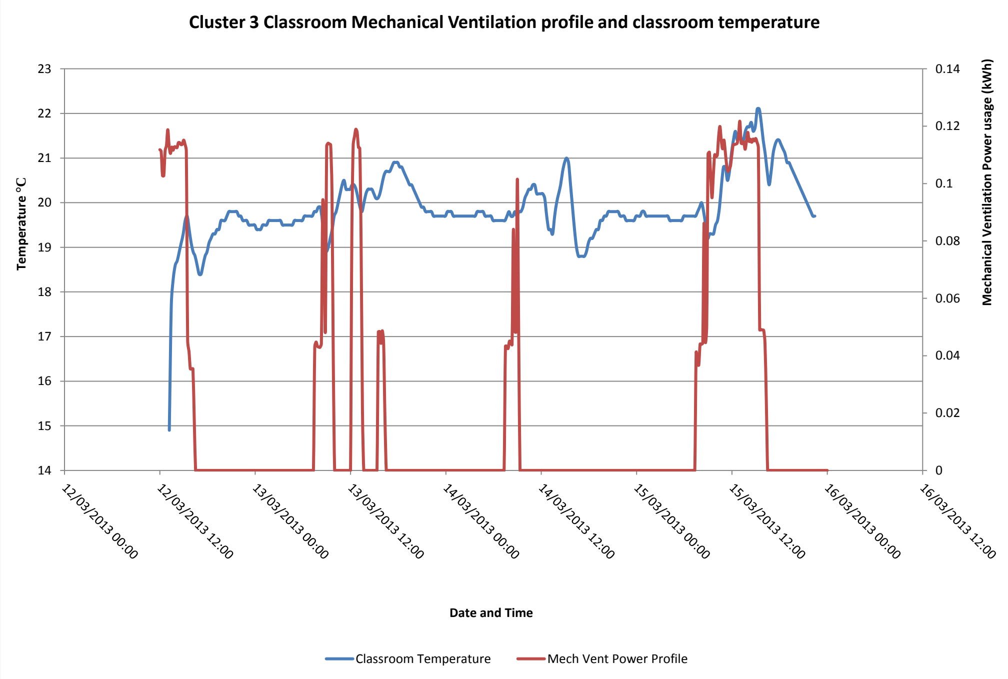
The ventilation strategy therefore satisfies these guidelines but there is a reliance on natural ventilation to achieve this - the performance of the mechanical ventilation is not meeting design intent. There are a number of explanations as to why the levels peak at high levels; the first of which is that it is believed the units were turned down to an operating level of 30l/s from 90l/s due to noise issues. To improve the effectiveness of the units, they could be set to an intermediate level of the required minimum fresh air the control should be reviewed in terms of where the outside air temperature is being measured and the time-switch settings.

Figure 51 Cluster 3 Classroom (a) - CO_2 levels during the period 12/03/2013 - 15/03/2013



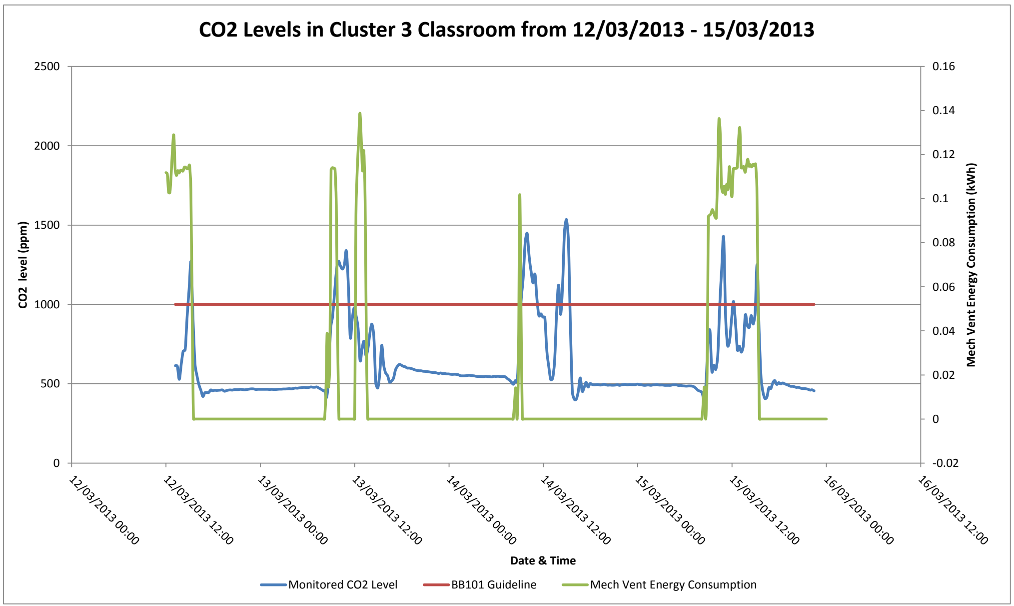
The pattern of mechanical ventilation operation is similar between Classroom (a) and (b) – on days of outside temperature less than 10°C the unit is running continuously. On days where the outside air temperature rises through the set point an intermittent pattern is observed. The rise in CO_2 doesn't appear to be immediately arrested by the action of the mechanical vent.

Figure 52 Cluster 3 Classroom (a) - Mechanical Vent Power consumption action plotted against internal temperature during the period 12/03/2013 - 15/03/2013



Another factor could be that the natural ventilation strategy is not being implemented as it should be by the occupants of the room, with the skylights and windows remaining closed when the classrooms get stuffy. It is recommended that all new teachers and supply teachers are made aware of the natural ventilation strategy to ensure there is sufficient ventilation into the classrooms. Figure 52 shows the energy usage of the mechanical ventilation system and the external temperature over the same period.

Figure 53 CO2 levels in Cluster 3 Classroom (b) from 12/03/2013 - 15/03/2013



The monitored CO_2 levels in Cluster 3 Classroom (b) are shown in Figure 53 above. Although the levels are much lower than the adjacent classroom, they still peak above the average of 1500ppm guideline. The difference in CO_2 levels in the two adjacent classrooms may be because the natural ventilation strategy is implemented differently by the class teachers as the two mechanical ventilation units have very similar energy consumption profiles. The children in this classroom are also of a younger age group which may affect the amount of CO_2 produced over the course of the day, or there were fewer children in this classroom.

Figure 54 Cluster 3 Classroom (b) Mechanical Ventilation Power Profile plotted against internal temperature

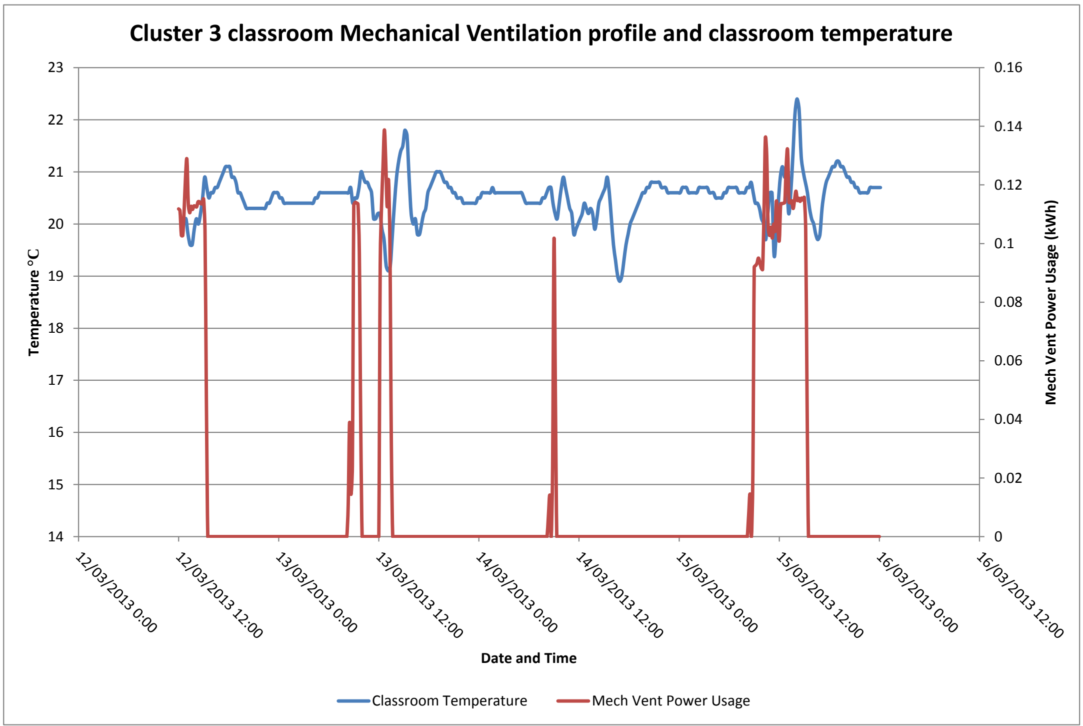
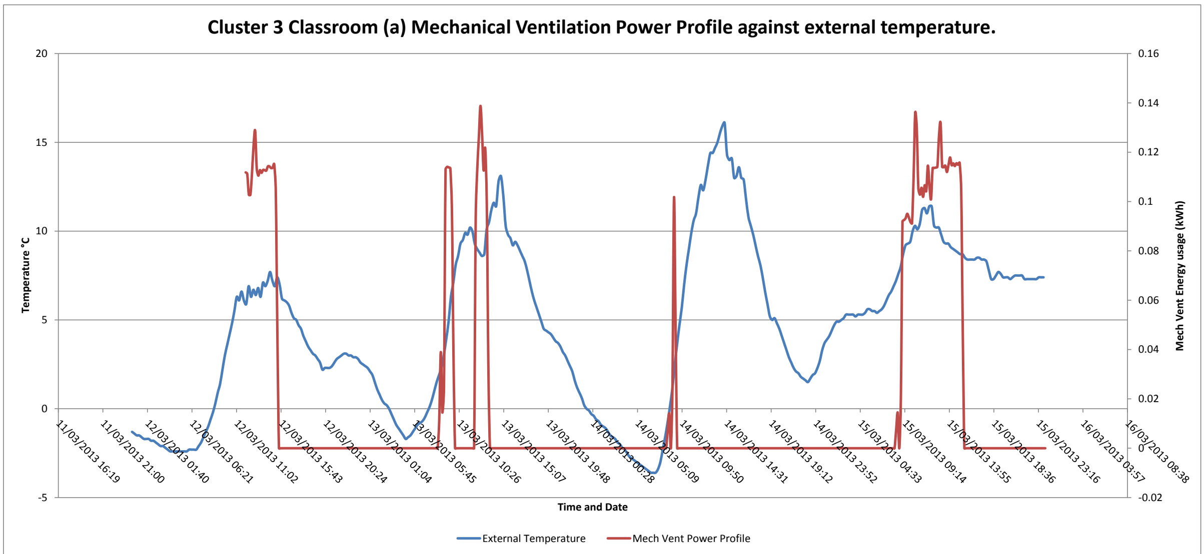


Figure 55 Cluster 3 Classroom (b) Mechanical Ventilation Power Profile



3.2.1. Key findings for the Teaching Cluster Mechanical Ventilation Systems

The control of the mechanical ventilation systems whilst is nominally straightforward - released on low outside air temperature and will run if during teaching time is showing sporadic behaviour. The teaching staff used openable windows to improve the freshness of the space in the depths of winter rather than rely on the mechanical ventilation system.

The control of the mechanical ventilation will need reviewed once enabled to run, fails to immediately arrest and stabilise the rise in CO_2 levels – here there is likely to be a trade-off between increased air change rates and noise generated by raising the air volume.

The effectiveness of the mechanical ventilation heat recovery (MVHR) will be dependent upon air leakage rate less e.g. than 5 $m^3/hr/m^2$ @ 50Pa but ideally nearer 3 $m^3/hr/m^2$. From the air tightness tests, see section 2.4 Cluster 3 was found to have air permeability of 3.6 $m^3/hr/m^2$ but Cluster 1 only achieved 7.0 $m^3/hr/m^2$. The contribution from the MVHR will be better in the tighter buildings than those with higher leakage rates.

6.3 Domestic Hot Water

In Clusters 1, 2 & 3 point of use electric hot water heaters – Aquapoint II 5, 10 and 15 litre capacity which have a nominal electrical rating of 2.2kW. These are located at each sink or basin range and the water temperature is regulated using an internal temperature sensor.

In Cluster 4 hot water is generated from the LTHW primaries in storage cylinders in the plant room. The energy for heating the water comes from two sources;

- Gas Boilers
- Solar Thermal

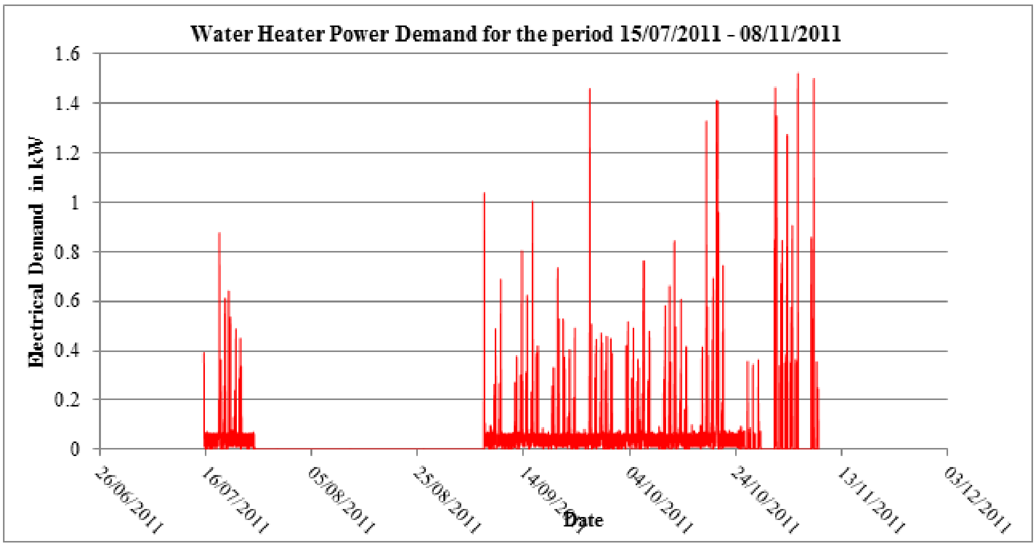
The gas boilers heat the duty cylinder to ensure heat maintenance for legionella control. This circuit also operates on a pasteurisation circuit for the solar pre heat cylinder which will heat the cylinder up to 60°C for 1 hour every day.

Thermostatic mixing valves have been provided at each wash hand basin and classroom sink to enable temperature control. Mixing valves come complete with integral non return valves, strainers and swivel inlet connections. The hot and cold services are isolated with ball-o-fix valves at the connection to the mixing valve. The thermostatic control has been commissioned and set up to deliver a maximum temperature of 43ºC.

6.3.1 Cluster 2 DHWS Water Heater

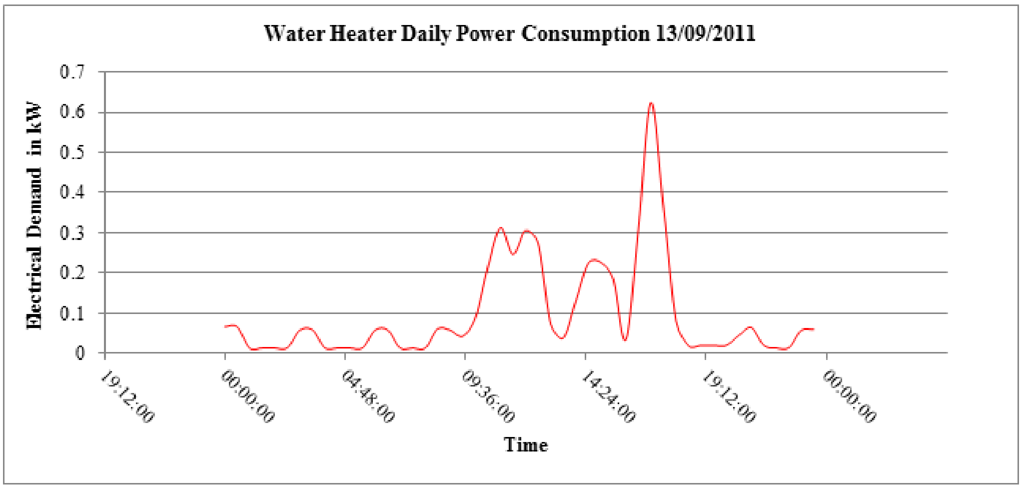
The period of measured data for the water heater shows a constant low load to begin with, and then no loading for 41 days over the summer holiday period. From the 06/09/2011 until the 25/10/2011 there is a constant low load during the day and night and then after this period there are low loads during the day but no loads at night.

Figure 56 Water Heater Power Demand for the period 15/07/2011 - 08/11/2011



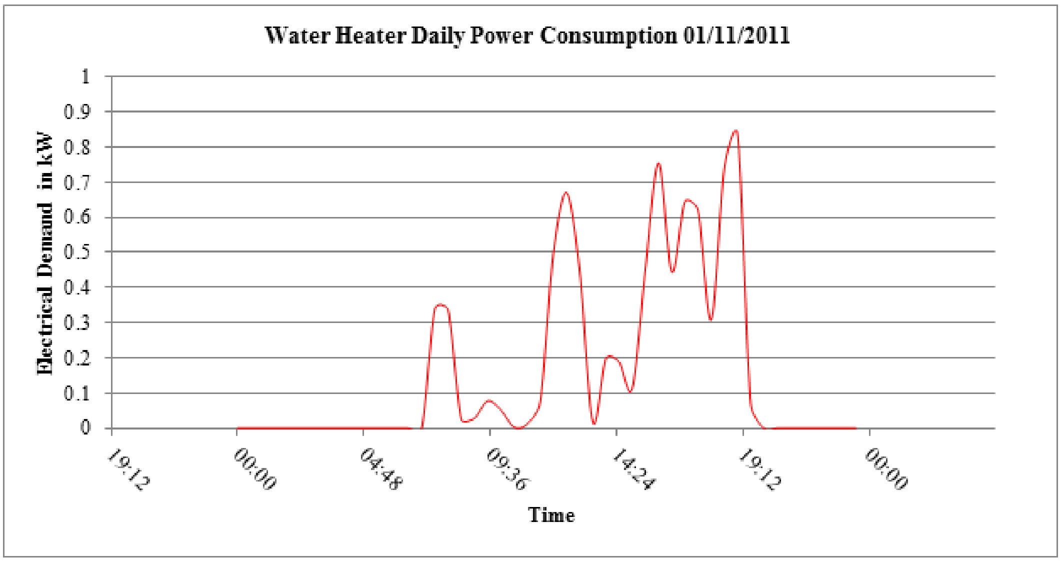
In Figure 57 there is better management of the out of hours use with the heater being isolated to avoid the quiescent load. There are two distinct peaks, one during the morning as classes commence the other at the end of the occupancy when there cleaning activities and the system recovers the modest storage volume in these point of use heaters.

Figure 57 Water Heater Daily Power Consumption 13/09/2011



In Figure 58 there is better management of the out of hours use with the heater being isolated to avoid the quiescent load.

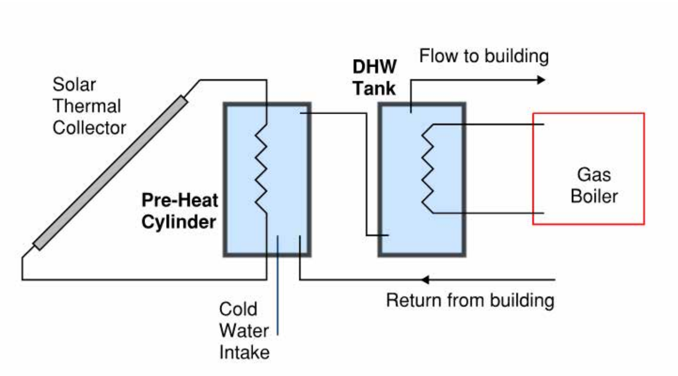
Figure 58 Water Heater Daily Power Consumption 01/11/2011



6.3.2 Thermal Solar Panel

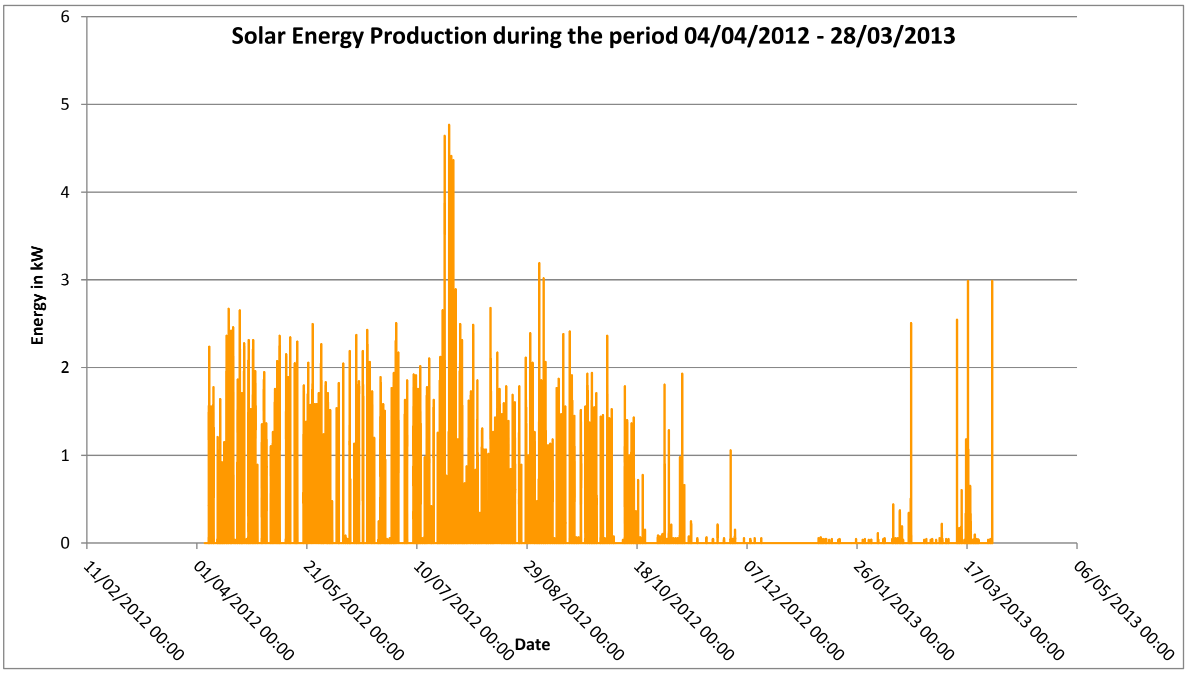
There are two Heliostar 3m^2 flat plate thermal solar panels located on the roof of Cluster 4 giving a total panel area of 6m^2, see Figure 59 Cluster 4 Solar Thermal Pre-heat System for the Domestic Hot Water. The panels provide preheating of the water for DHWS used in Cluster 4. A programmable controller activates the pump in relation to the sensor located at the solar panels, a heat sensor on the flow/return pipework and a temperature sensor at the solar cylinder.

Figure 59 Cluster 4 Solar Thermal Pre-heat System for the Domestic Hot Water



The thermal solar system output is utilised to preheat the DHWS feed cold water and the output profile is shown in Figure 60. For the majority of the spring and summer period the panels were delivering approximately 2.5kW of heat. For a total of 6m^2 of panel this indicates about 400W/m^2 peak output with a thermal efficiency of approximately 50%.

Figure 60 Thermal solar panel output for the period April 2012 to March 2013



The annual useful solar thermal contribution to the DHWS is found to be 1,786kWh for this period which represents a panel output of 293 kWh/m^2 of panel area. The energy generated was calculated by monitoring the difference in temperature between the flow and return to the collector and the flow rate through the collector. If the mean incident annaul solar irradiation is of the order of 1000kWh/m^2 for the site location this represents a thermal efficiency of approximately 30% which is below what might expect for this type of collector – 40 to 50%. The reasons for the discrepency are likely to be losses from the collector and distribution pipework and attenuation of solar radiation due to dirt build up on the glazed facing plate.

Table 13 Monthly Solar Thermal Output for 2012/2013

Year	Month	Heat generated kWh
2012	July	499
	August	459
	September	349
	October	117
	November	25
	December	2
2013	January	11
	February	9
	March	42
	April	39
	May	129
	June	103
Total		1786

6.3.3 Key findings for the DHWS Solar Thermal

Teaching Cluster DHWS is typical at 5.6kWh/m^2 consisting of the hand washing in the course of the day and cleaning speak after school has finished. Cluster 4 is higher because of the DHWs related to the Catering use. If we look at the contribution that the solar thermal system gives then the annual DHWS energy use is estimated at:

Cluster 4	9.0kWh/m^2	(gas)
Teaching Clusters 1,2 &3	5.6 kWh/m^2	(elec)
Solar Thermal	0.9 kWh/m2	(heat)

If we convert that to heat using a thermal efficiency of 80% and electric heat efficiency of 95% DHWS heat amounts to:

Cluster 4	7.2kWh/m^2	(heat)
Teaching Clusters 1,2 &3	5.3 kWh/m^2	(heat)
Solar Thermal	0.9 kWh/m2	(heat)
Total DHWS heat	13.4 kWh/m^2	

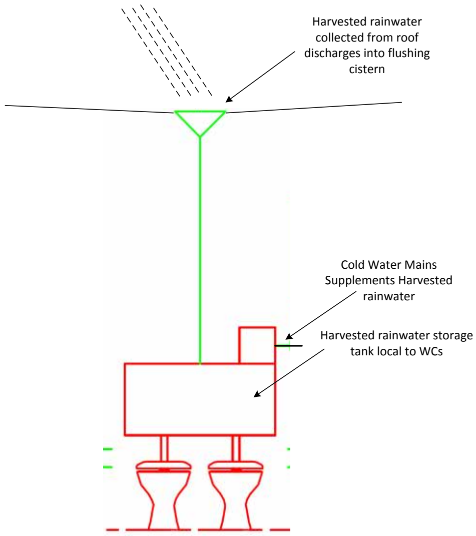
The solar panels are providing approximately 7% of the DHWS energy used by the School. The monthly aggregated heat output is summarised in The annual useful solar thermal contribution to the DHWS is found to be 1,786kWh for this period which represents a panel output of 293 kWh/m2 of panel area. The energy generated was calculated by monitoring the difference in temperature between the flow and return to the collector and the flow rate through the collector. If the mean incident annual solar irradiation is of the order of 1000kWh/m2 for the site location this represents a thermal efficiency of approximately 30% which is below what might expect for this type of collector – 40 to 50%. The reasons for the discrepency are likely to be losses from the collector and distribution pipework and attenuation of solar radiation due to dirt build up on the glazed facing plate.

Table 13. The annual useful solar thermal contribution to the DHWS is found to be 1,786kWh for this period which represents a panel output of 293 kWh/m2 of panel area. Principal periods of solar contribution are in peak summer months and early autumn, spring is low and winter yield is negligible

6.4 Rainwater Harvesting System

A rainwater harvesting system has been provided to deliver rainwater to WC cisterns throughout Clusters 1, 2 & 3, see Figure 61. Filtered rainwater is collected off the roof of the Cluster and stored in rectangular pre-fabricated polypropylene tanks for use in the WC's. Each tank has clear viewing turrets on the front of the tank. Each tank has a cold main supply to preserve the level within the tanks in the event of insufficient rain.

Figure 61 Rainwater Harvesting System



6.4.1 Key findings for the Rainwater Recovery System

There were problems with the rainwater harvesting system shortly after handover. Water hammer was experienced on the mains water make-up valves due to high mains pressure in that part of the network ~ 7bar. These were replaced with *Torbec* valves which were more resistant to the high mains water pressure which rectified the problem. Additional problems were found on water over flowing from the cisterns into the pans due to faulty flushing valves. These were also replaced to successfully solve this issue.

The most chronic issue was the lack of maintenance carried out on the system. There seemed to be no maintenance procedures in place for carrying out regular cleaning of the inlet filters. The roof inlets contain a small filter that should be accessed by lifting the leaf guard, removing the filter bag and flushing through with clean water. The whole process could be carried out in a few minutes. The responsibility for cleaning the filters was not defined and so they went untended.

As regards their contribution to water use performance, this can only be viewed in terms of total water usage which varied month on month between 5 to 8 li/p/day, see Figure 12. Whilst this is lower than the Institute of Plumbing benchmark for Schools of 15li/p/day, it is higher than the design level of 3,5li/p/day. So like a number of other features of the building an impact can be seen but it is not operating at its optimum.

6.5 Energy Metering

One of the key elements of a low energy building are the systems that are put in place to give the building operator visibility of how it's running so that effective management can be exercised. The design intent was to have such systems but these were 'culled' in late value engineering and never fully recovered thereafter. Modbus meters were installed but the interface with the building operator was neglected.

The LV switchgear is contained in a weatherproof enclosure behind Cluster 2. The utility fiscal meter is also located in this enclosure. The LV switch-panel was built with check meters on the main incomer and on the 9 sub-mains. The sub-mains meters are networked together for data over an RS485 network connected to an EGX 300 Schneider gateway device which runs the local network and stores consumption data for a little over a month. The meter on the main incomer is not networked to the EGX gateway. Although the record drawings indicate the meter on the main incoming supply is connected to the BMS, the BMS was value engineered out of the project.

The switchgear has 9 Modbus sub-meters that are connected by a local network to a Schneider EGX300. Initially the EGX was not connected to the school IP network however subsequent to a conversation ScoMIS (ICT service provider for Devon County Council) we arranged for IJ Cannings, ScoMIS's preferred data cabling contractor to install a data cable from the switchgear to a patch-panel in Cluster 1 through existing ducts and cable draw-pits. The sub-main meters are now accessible and can be interrogated through the school IP network on a PC in the school library. Due to data security concerns were not able to establish a remote reading facility through the fire wall protecting the school's IT systems.

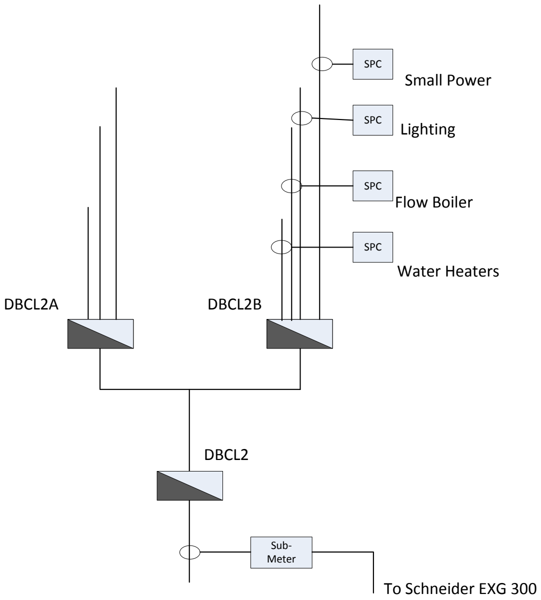
To resolve this IT manager for the school helped us by sending monthly files of data from the fixed metering. During the monitoring period the school caretaker took manual monthly readings from the main fiscal meter for an additional check on monthly meter advances.

6.6 Sub-Metering Power Profilers

To supplement the fixed metering system portable power profilers were installed to understand the energy breakdown in more detail. Cluster 2 was chosen for the first test period (Quarter 1 and 2) and consumption data was collected as indicated below, see Figure 62.

The data was collected from these portable data loggers on flash memory cards and the processed data is presented as traces. Interestingly, on occasions when the school is unoccupied, the energy flow is indicated as negative. It is thought that this represents those occasions when the Photovoltaic systems are generating more energy than is being consumed in that particular cluster. This will be investigated further to prove this theory.

Figure 62 SPC locations in Cluster 2



In addition the following loads are being monitored

- Kitchen AHU
- Kitchen Extract Fan
- IT Room DX Cooling Load.
- Water Heater
- Lighting sub-circuits
- Heat Recovery Unit
- Heat Pumps
- Flow Boilers

As can be seen from Figure 45 the local distribution boards did not segregate lighting and small power circuits and these ways had to be gathered downstream of the board for monitoring with the portable meters.

6.7 Supplementary Metering

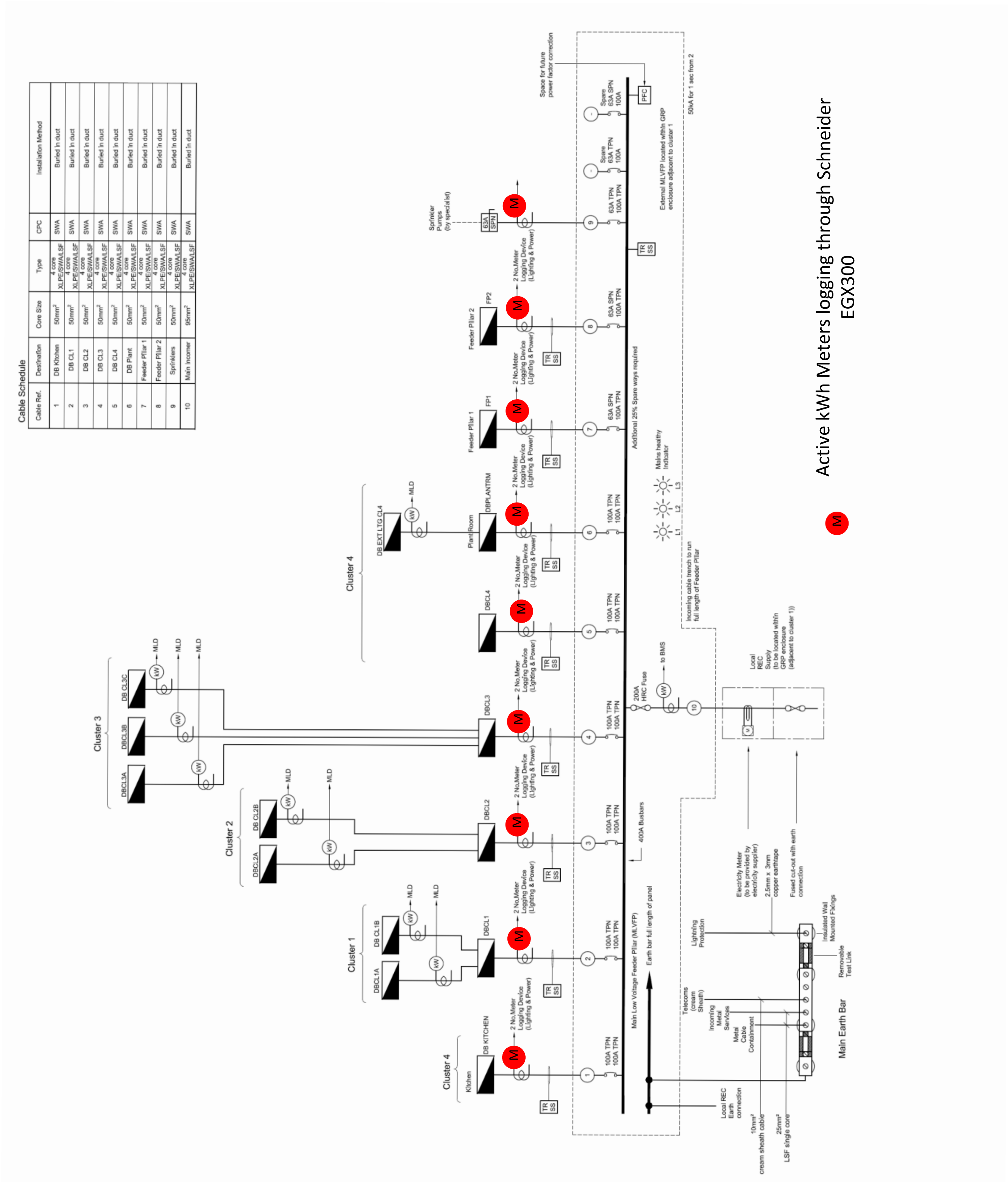
The classrooms have local "Owl" meters, these display the total amount of power used in the relevant cluster. They are intended for educational use only, see Figure 63.

Figure 63 'Owl' Power Classroom Meter

Sender box mounted on right hand side of DB

Classroom display

Figure 64 LV Distribution Schematic



Cable Schedule

Cable Ref.	Destination	Core Size	Type	CPC	Installation Method
1	DB Kitchen	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
2	DB CL1	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
3	DB CL2	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
4	DB CL3	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
5	DB CL4	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
6	DB Plant	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
7	Feeder Pillar 1	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
8	Feeder Pillar 2	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
9	Sprinklers	50mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct
10	Main Incomer	95mm²	4 core XLPE/SWA/LSF	SWA	Buried in duct

6.7.1 Key findings for the Sub-Metering System

The sub –metering system is critical for any building to perform at its best but even more so for high performing buildings. A good provision for sub-metering was made in the original design but this suffered in the value engineering exercise that was carried out at Stage G of the project. The original design intent was to connect Modbus sub-meters to the School wide BMS network with the capability to view metered data through web-pages.

Significantly at this point the metering communications network was 'culled' from the design. It was not subsequently passed back for re-design to find a functional compromise solution.

In schools the interface with the school care-taker is very important as they will generally non-technical and have many other duties to carry out. As a consequence they will require information in a readily digestible form so that decisions can be made. The interface between metering system and care-taker needs to be carefully thought through to be effective. A dash-board type interface will relate information as to whether the school is working to benchmarks or requires action.

At Dartington the system was left in limbo and for the BPE work we have a working network were IP addressable meters can be accessed through the School intranet to gather energy information which the staff now do. It however needs refinement for day to day management by the staff once the BPE project finishes so that it can be used effectively for benchmarking the School and diagnosing problems when they arise.

6.8 Lighting Systems

6.8.1 General Lighting

Generally all luminaires are high efficiency fittings – T5 fluorescent lamps with electronic ballasts. In areas where dimming control has been provided this is achieved by the use of digital addressable lighting interface (DALI) dimming. The majority of fittings have been surface mounted with a small number of wall mounted fittings at various locations.

The fittings have a combination of hard wired and "plug and play" connections, which means there is a combination of lights attached to the building structure and moveable lamps so that the lighting can be easily reconfigured to suit changes in room layout or use. The system comprises of a combination of local lighting distribution units generally mounted within the plant rooms, which then feed the local fittings via the containment system.

6.8.2 Local Lighting Control

The lighting is controlled using a number of methods including occupancy sensing, day light sensing, dimming and local switching. Where switches have been installed these are either wall mounted or located on the dado trunking. Occupancy sensing and daylight sensing equipment has been mounted on the ceiling.

In the teaching spaces and offices, dimming has been installed; the dimming is achieved by pushing in the local retractive switch, the light levels will then either increase or decrease as necessary.

Daylight linked dimming is provided in the classrooms and offices; in these areas the lighting will sense occupancy by passive infrared (PIR) sensors and the light levels using modulated light level sensors and then control the lighting levels to the pre-set levels so that no user intervention is required.

Presence detection has been installed in all classrooms, toilets, offices and circulation areas. PIR sensors detect movement to control the lighting, switching off after a predetermined period so that no user intervention is required.

Elsewhere manual controls were provided.

6.8.3 Teaching Cluster Lighting

The metered data during the measured period of August 2013 to January 2013 is shown in Figure 65. The loading profile shows a higher demand in winter than summer as expected as day-lighting linking control takes effect. There are also low demand periods when the pupils are on their summer holidays. The baseline stays at around 0.5W/m^2; this accounts for the PIR and daylight dimming sensors which have a small parasitic load. Note that the W/m^2 power demands are expressed against the teaching areas they serve not the whole school.

Figure 65 Lighting Power Demand for Cluster 3 C (Treated Area =214m^2) for 19/08/2012 to 17/12/2012

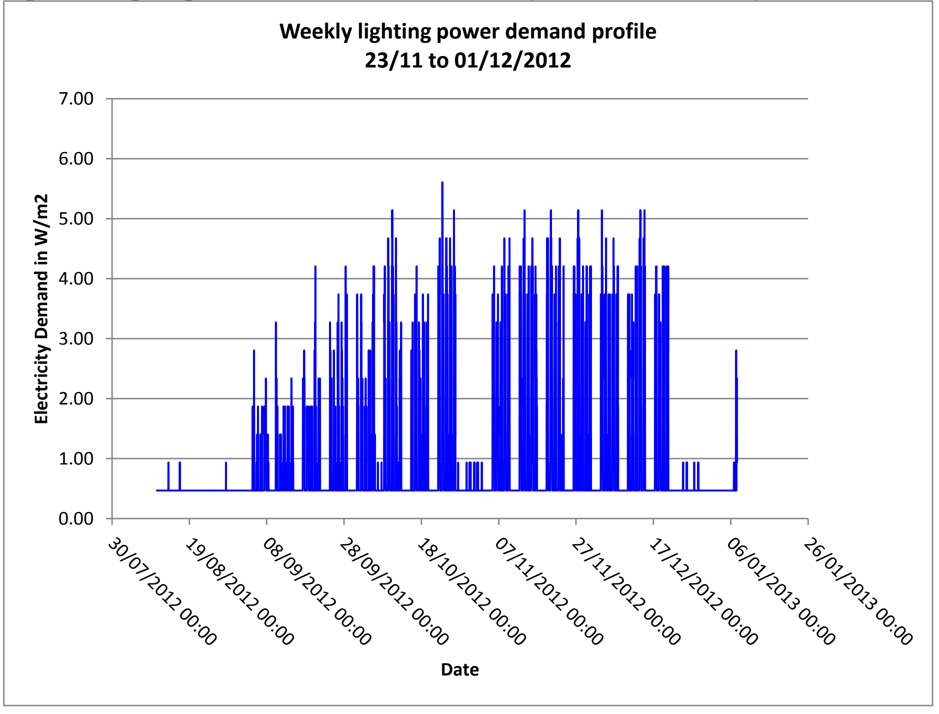


Figure 66 shows the demand profile for zone B in Cluster 3. This profile shows a higher peak at 8.5W/m^2 but illustrates the control characteristics. In both profiles, control in response to daylight is evident particularly in September.

Figure 66 Lighting Demand Profile for Cluster 3 B (Treated Area=150m^2)

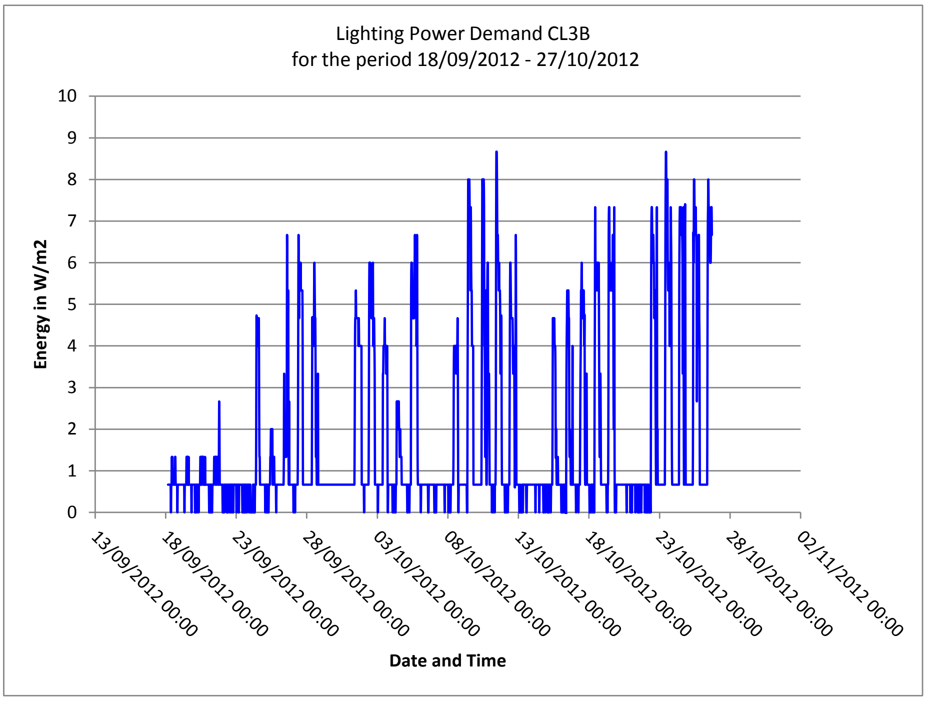
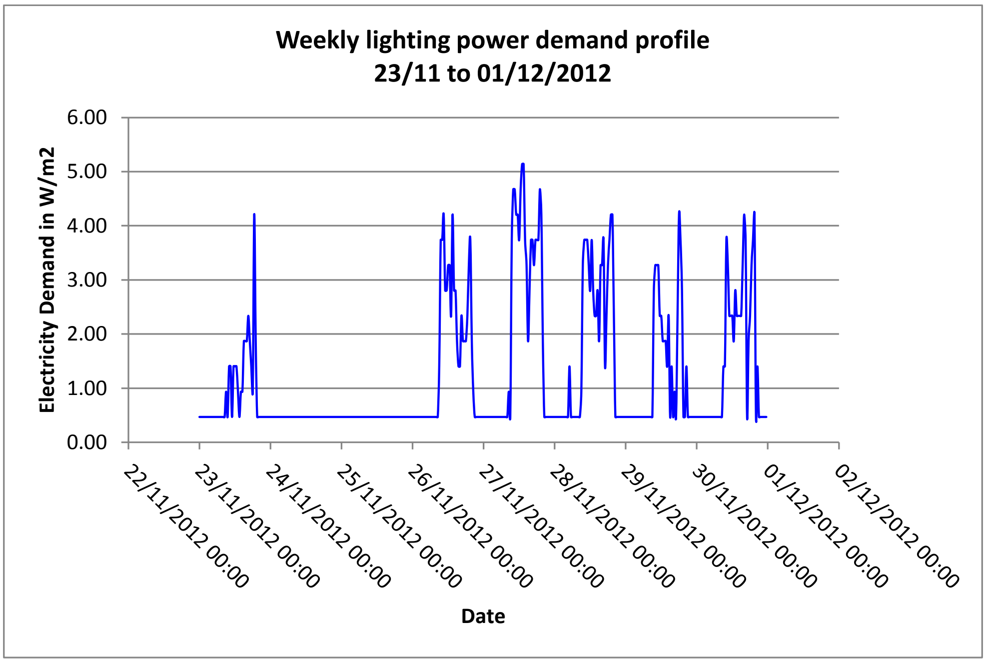


Figure 67 shows the weekly power profile for winter time lighting control. There is clear evidence of the impact of daylight dimming control and switching in the course of the day which reduces the average demand to approximately 2.5W/m^2.

Figure 67 Lighting Weekly Power Demand 23/11 – 01/12/2012 (Treated Area=150m^2)



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6.8.4 Key Findings for the Lighting Systems and their Control

The lighting energy consumption was found to be 7.4kWh/m^2 which is about half of typical lighting energy use in primary schools (Energy Consumption Guide for Schools ECG073 Carbon Trust), see Table 10. This was due in part to the specification of high efficiency lamps such as T5 fluorescent and the control systems which modulate to occupancy and prevailing day-light levels.

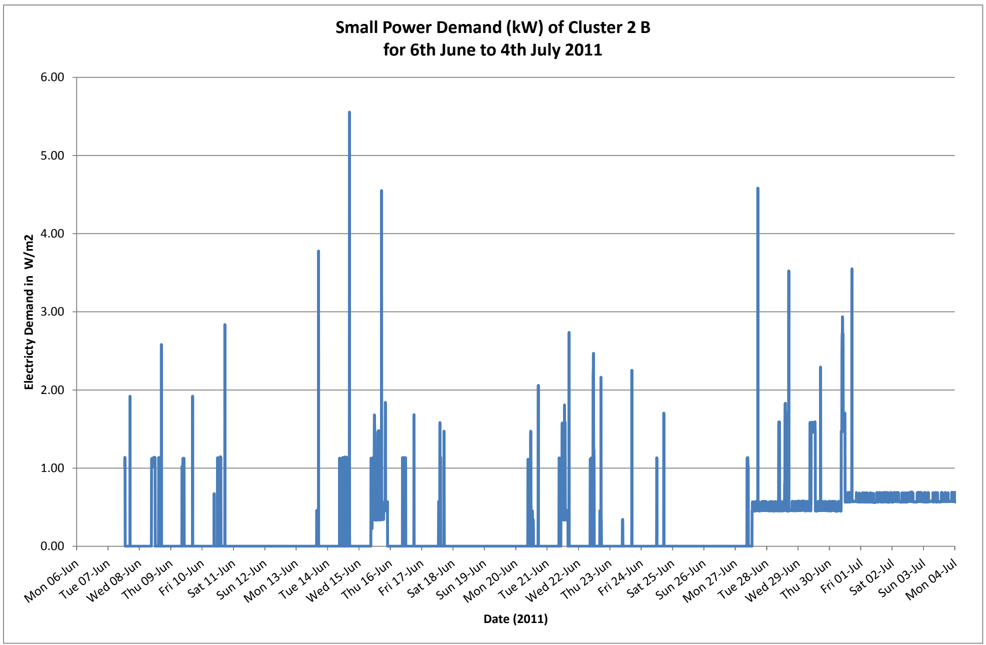
The control over lighting was scored above the national benchmark in the occupant satisfaction survey. There was a degree of forgiveness with respect to the lighting control, e.g. there were staff comments that the lighting was easily altered and effective and this was despite the intermittent failure of controls where programming was corrupted leading to dimming or switching off at inappropriate times

The day-lighting levels in the building were generally liked by the staff who noted this in the survey responses. There were some comments that noted the blinds have to stay down early morning because of glare issues

6.9 Small Power Systems

The small power use is low and a second order load in the Teaching Cluster limited to intermittent use of white boards, projectors, and cleaning equipment etc. Figure 68 shows a typical profile where there is base load of approximately 0.5W/m^2 peaking periodically at 4.5W/m^2.

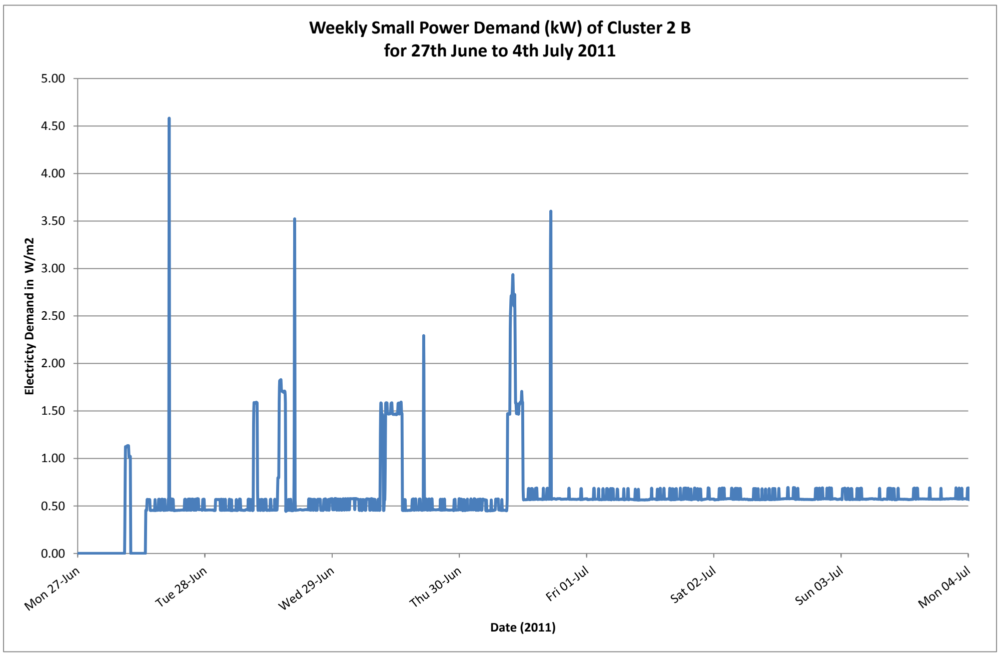
Figure 68 Small Power Energy Demand for Cluster 2B (Treated Area=267m^2) the Period 7/6/2011 – 4/7/2011



Each of the teaching areas has been provided with a key switch (in a red surround). When operated, this switch will isolate the general power supplies. However, the Velux windows, Dry Wipe board, cleaners' sockets and lighting supplies will be unaffected. This has facilitated the tight management of small power reflected in these results.

There is evidence of likely use of the 'power-off' switch where consumption drops to zero, see Figure 68. Later in this period there is a base load appearing suggesting that the switch was not used.

Figure 69 Weekly Small Power Profile for Cluster 2B (Treated Area=267m^2)



6.9.1 Key Findings for the Small Power Systems

The annual small power consumption for the School is low at 2.0 kWh/m^2 which reflects the effective management of plug equipment. The power-off switch provides shut-off of non-essential plug loads which is used for part of the monitoring period but a quiescent load appears at about 0.5W/m^2 (120W). This facility appears to have been employed but its use is intermittent.

6.9.2 Kitchen Air Handling Unit (AHU) and Extract Fan

The main kitchen is located in Cluster 4 the data shown here is for the kitchen ventilation system. The loading profiles of the kitchen AHU and extract fan can be found below for the entire measured periods and detailed daily profile. The profile shows the problem of poor scheduling which also plagued the heat pump plant.

Figure 70 shows a fluctuating electrical load; during this measured period electricity was being consumed for approximately 1 hour every 2-3hours throughout the day and night, including over the Christmas period.

Figure 70 Kitchen AHU Power Demand for the period 08/11/2011 - 26/01/2012

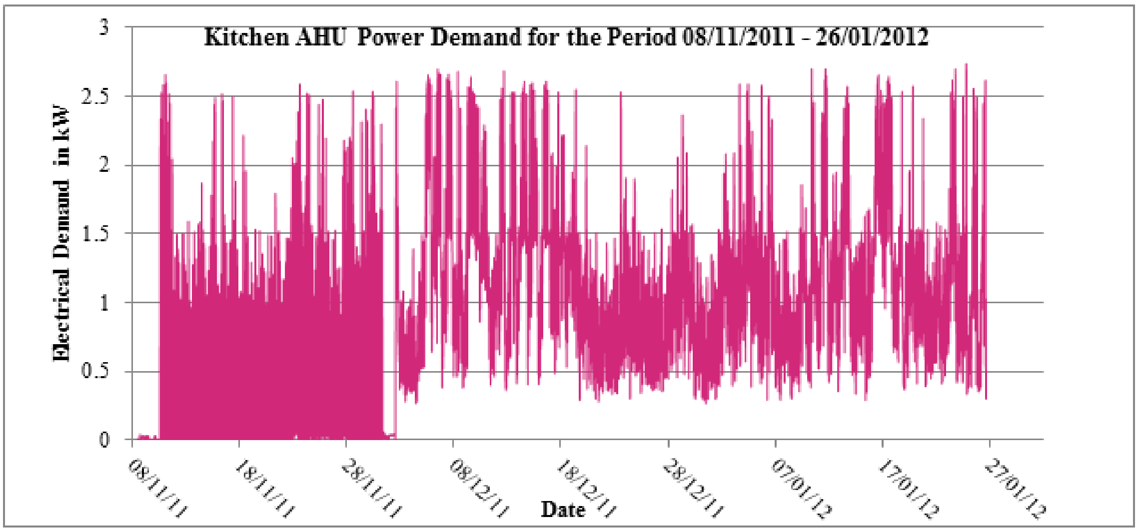
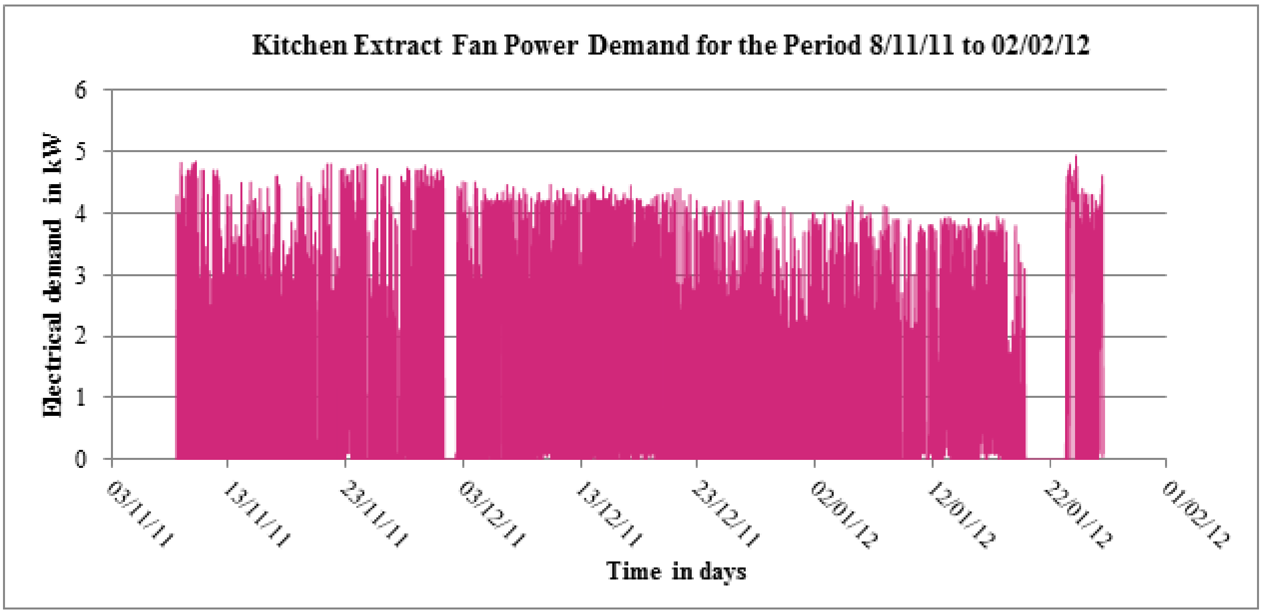


Figure 71 Kitchen Extract Fan Power Demand for the Period 8/11/11 to 02/02/2012



The peak energy demand was 2.74kW which occurred on 24/01/2012; after 02/12/2011 the energy consumption does not fall to zero and so is never fully turned off, as shown in the daily power consumption in Figure 72. The kitchen extract fan shows a similar cyclic load profile as it consumes energy for approximately 1 hour every 2-3hours as shown in Figure 73.

Figure 72 Kitchen AHU Daily Power Consumption 13/12/2011

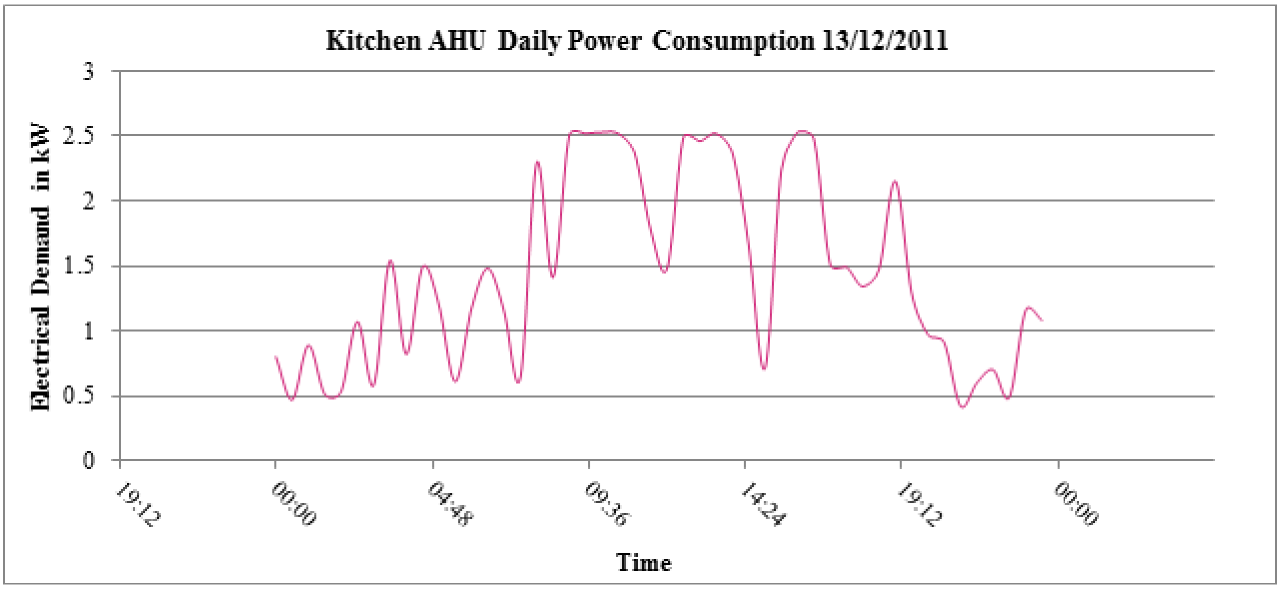
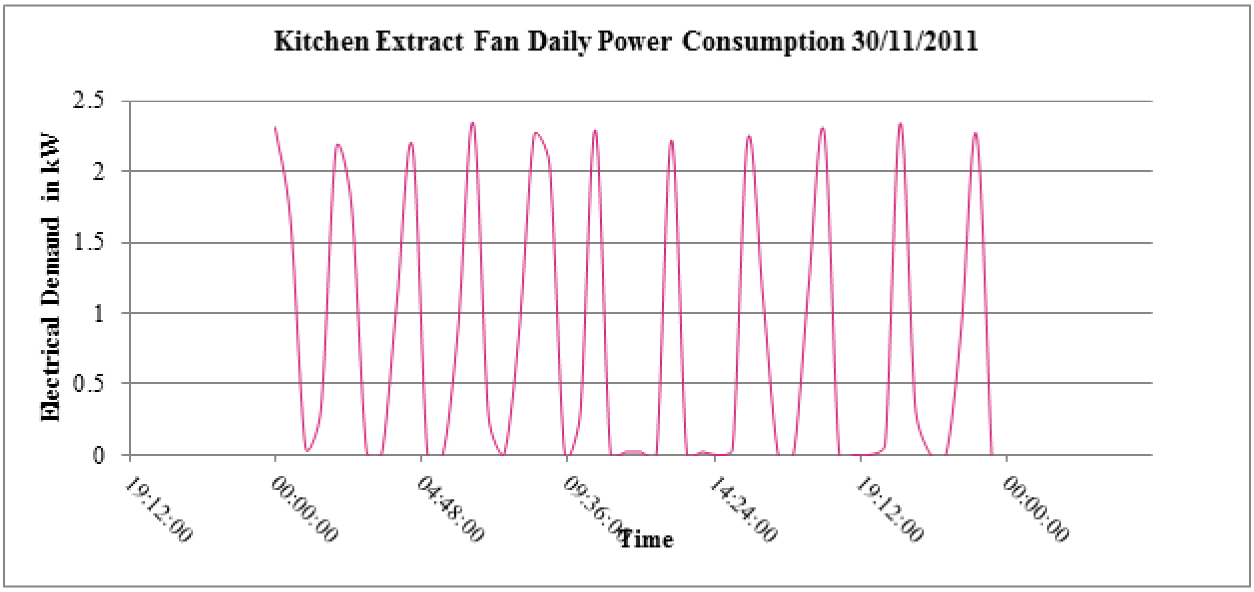


Figure 73 Kitchen Extract Fan Daily Power Consumption 30/11/2011



6.9.3 Key Findings for Kitchen Ventilation System

The system is showing excessive operation and the control schedule set on the Trend IQA should be returned to its correct setting. This will reduce the energy consumption of the kitchen AHU and extract fan, both systems could be turned completely off when the kitchen is not in use, which would include at night and over holiday periods.

6.10 Photovoltaics

Clusters 2, 3 & 4 are fitted with PV panels with a peak output rated at 14.16 kWp. The annual measured electricity production is approximately 13,000kWh (918kWh/kWp), see Figure 74.

Figure 74 PV Panels on Teaching Cluster 2

Each array consists of 10 x Sharp ND-200 UC1 Polycrystalline panels each with a maximum output of 200W. This equates to a total PV area of approximately 114m^2. Data on electricity generation by the Photovoltaic system is available on the SMA Sunny Portal and visible at

http://www.sunnyportal.com/Templates/PublicPageOverview.aspx?plant=ff7ff9c8-ffe7-4af3-944e-32a00feefce4&splang=en-US

The SMA portal communicates with the 8 inverters used in the Dartington arrays. The system flags up any out of range values for early warning of system faults. The metering system was validated against standard benchmarks for this specification of panel. Expected yield is based upon the 20 year average irradiation data for this location.

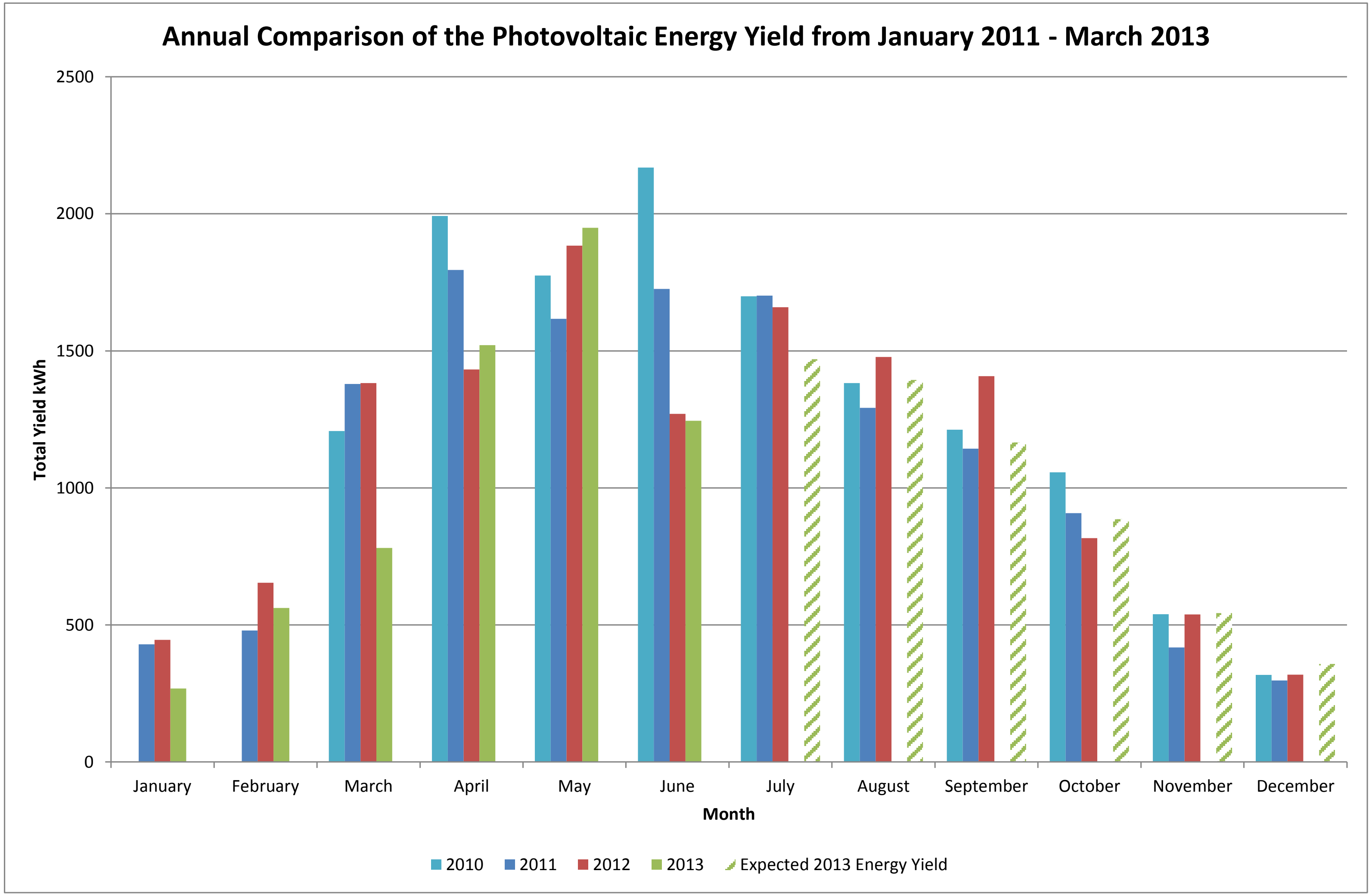
6.10.1 PV Annual Yield

Table 14 shows the photovoltaic analysis to date since commissioning on 18/03/2010.Figure 75 shows the annual PV yield in 2010 to 2013, as collected by the remote monitoring system. It shows that the annual yields were higher than expected during the summer months and similar values to the expected yield in the winter months in both 2010 and 2011.

Table 14 Photovoltaic Analysis

	Total Yield kWh												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
2010			1207.28	1992.3	1774.85	2168.7	1699.26	1382.37	1212.52	1056.82	539.13	317.99	**13351.22**
2011	428.93	479.89	1378.88	1795.6	1617.23	1725.99	1701.71	1292.02	1143.49	907.76	417.82	297.72	**13187.04**
2012	445.24	653.99	1382.31	1431.89	1884.06	1270.58	1659.36	1477.55	1407.96	817.13	538.05	318.89	13287.01
2013	267.92	562.35	780.75	1521.26	1948.89								
													32565.97
Mean value	380.7	565.41	1380.6	1739.93	1758.71	1721.76	1686.78	1383.98	1254.66	927.24	498.33	311.53	13609.62
Year portion	2.84%	4.22%	8.81%	12.57%	13.48%	12.85%	12.59%	10.33%	9.36%	6.92%	3.72%	2.32%	100.00%
Yield expectations	460.74	703.43	1122.28	1316.92	1463.52	1437.65	1469.68	1393.3	1165.4	885.75	543.28	357.26	12319.2

Figure 75 Photovoltaic Energy Yield Annual Comparison 2010 to 2013



6.10.2 Key findings on the Performance of the PV Arrays

The mean annual yield from the PV arrays was found to be 12,545 kWh which represents 7.4 % of the total electricity used in the period 2012/13. The contribution from the PV is near to the expected output for this type of array on these orientations which is approximately 1000kWh/kWp.

Since coming on-line in the arrays have delivered a consistent output. Interestingly the months of April and May have shown high outputs reflecting the impact of solar altitude and roof pitch. One would have expected the symmetry effects of solar geometry to also show high outputs in August and September but this not so. The output from the array will be affected by ambient temperature and this difference in performance may be explained by the higher ambient temperatures experience in late Summer early Autumn compared to spring.

7 Key findings from Occupant Engagement

Interviews were held with the Head Teacher, Caretaker and representatives from the Board of Governors to obtain feedback on how the School had been operating from a user's perspective. This was followed up with A BUS Occupant Satisfaction Survey that allowed us to compare these subjective responses against national benchmarks.

7.1 Staff Interviews

Workshop sessions were held with the school, the local education authority, the main contractor and M&E sub contractor, and the project administrator on the 27th September and 27th October 2010. Useful feedback from these sessions included observations both positive and negative:

- The school is appreciated architecturally and for its airy and light spaces by most observers. Most people who comment on window and sky-light blinds say they are effective.
- The Cluster 4 and the school office area in particular have problems with overheating
- A number complain about the distributed nature of the plan and the distance between buildings.
- Acoustics was sometimes a problem and a number of comments suggested that this was arising within teaching spaces. This may indicate that the reverberant sound in the space is a problem because of lack of sound absorption. This should be studied further. There is also a problem with sound transmission around the hall and walls.
- Defects with the Construction
    - Leaks through the flat roof
- Defects with the mechanical and electrical systems
    - Suspected high energy bills for gas and electricity, and the school was on a high tariff
    - Breakdowns in the heat pump underfloor heating system
    - Intermittent failures in the light control system
    - No facility to use the Modbus electrical sub-metering system
    - Problems with the Rainwater recycling cisterns
    - Overheating in the plant room

7.2 School engagement with Building Performance Team – Save it Campaign

In order to engage with the main users of the School, a ‘Save-It’ campaign was run by the BPE team, see Appendix D. The Save It Campaign Workshop was run on 12th March 2013 with three classes from Years 5 & 6. The children took part in an interactive presentation about different aspects of sustainable building design including sustainable building materials, green roofs, renewable energy production, energy saving lighting controls, rainwater harvesting and natural ventilation.

7.3 Building Use Study Questionnaire

A BUS Occupant Satisfaction Survey was carried out in July 2011 on School Staff. Of the 42 paper questionnaires that were handed out and 26 were completed- giving a response rate of 62%. Of the sample of 26 90% of the respondents were over the age of 30. The complete results are presented in Appendix C: Occupant Survey Results. A summary of the overall variables are shown in

Figure 76**.** There is generally above average satisfaction with School, noise being the exception and this largely triggered by cross-talk issues.

Figure 76 Summary of Overall Variables

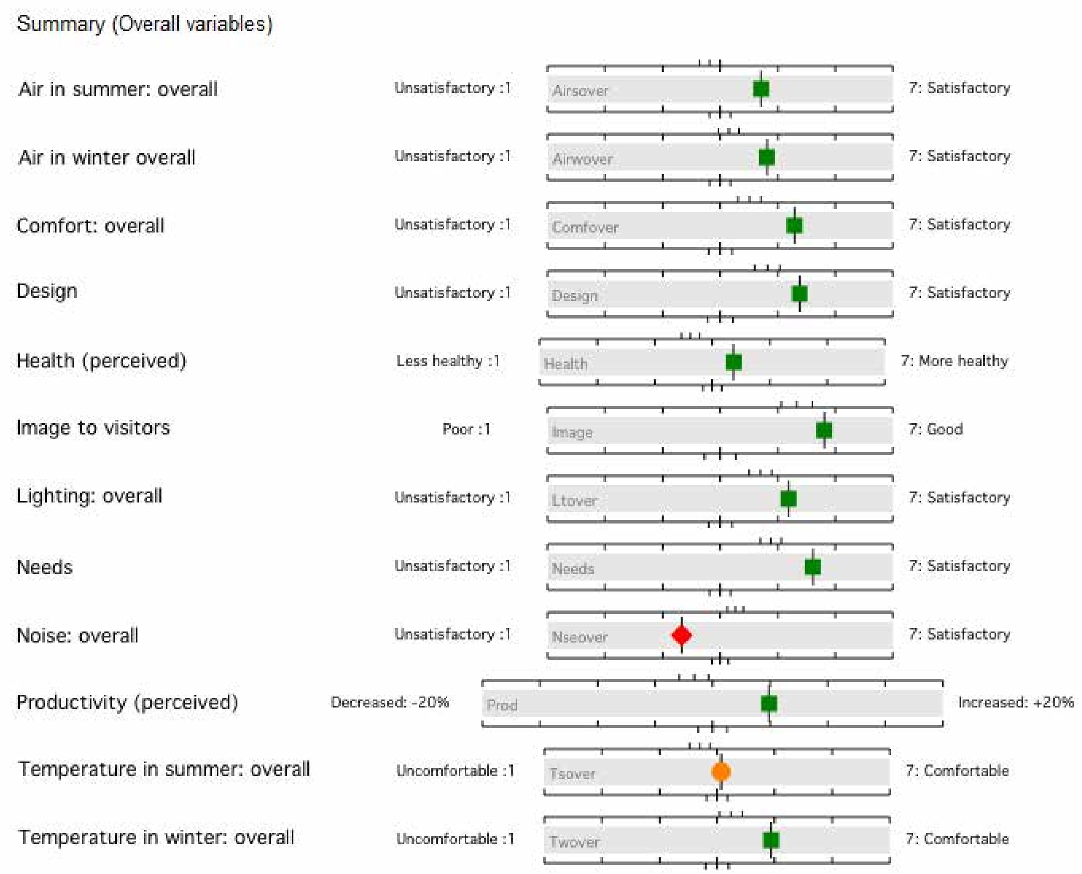
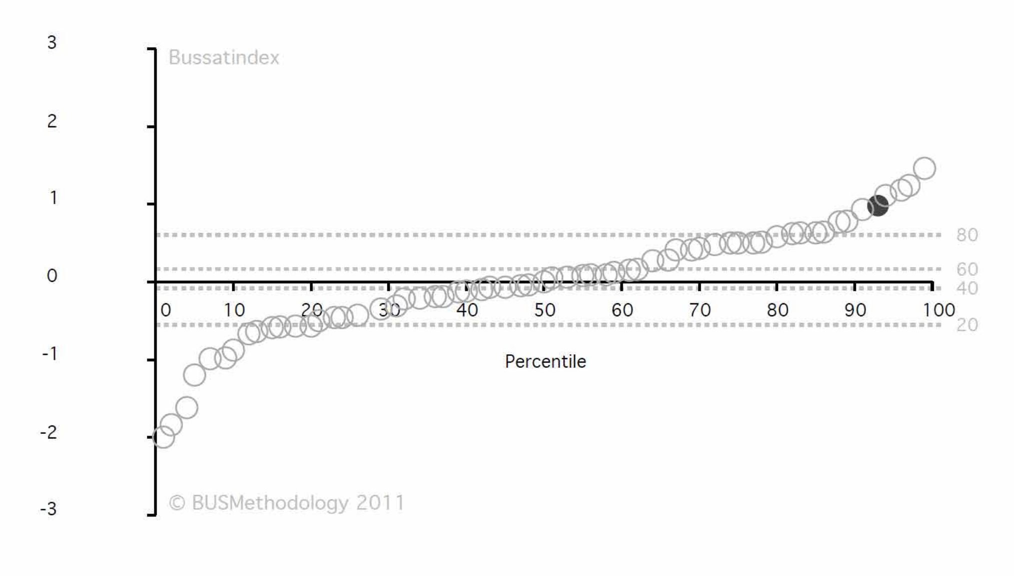
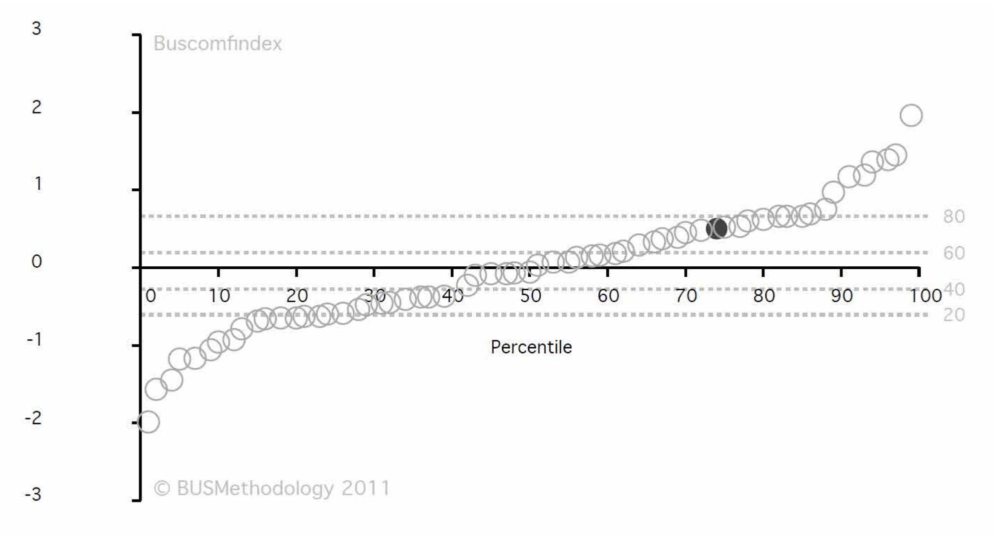


Figure 77 Satisfaction Index compared to BUS National Database Buildings



The building rates less well on its Comfort Index at the 74 percentile which encompasses thermal visual and aural comfort scores, see Figure 78.

Figure 78 Comfort Index compared to BUS National Buildings Database



7.4 Analysis of Detailed Responses

Examining the detailed results we found :

- Points which score green, indicating a better score than the total data base benchmark are:
  - Control over lighting
  - Air in summer overall
  - Air in winter overall
- Points which score orange, indicating a reasonable score are:
  - slightly stuffy air quality in summer
  - odours in summer
  - Slightly still air in summer
  - Slightly fresh air in winter
  - Control over cooling

- Points which are red, indicating a bad score are:
  - Air in summer is slightly dry (not sure what can be done about this as it is naturally ventilated in the open countryside)
  - Odour in summer and winter
  - Overstill air in winter

Air in Summer
Although the overall score for the air in summer was above the benchmark responses to specific questions such as stuffiness and odours scored below. This is an indication of the forgiveness that the responder has. Judging by the comments made on specific air quality issues this was driven by the experiences in Cluster 4 rather than the Teaching Clusters which were perceived to be light and airy.

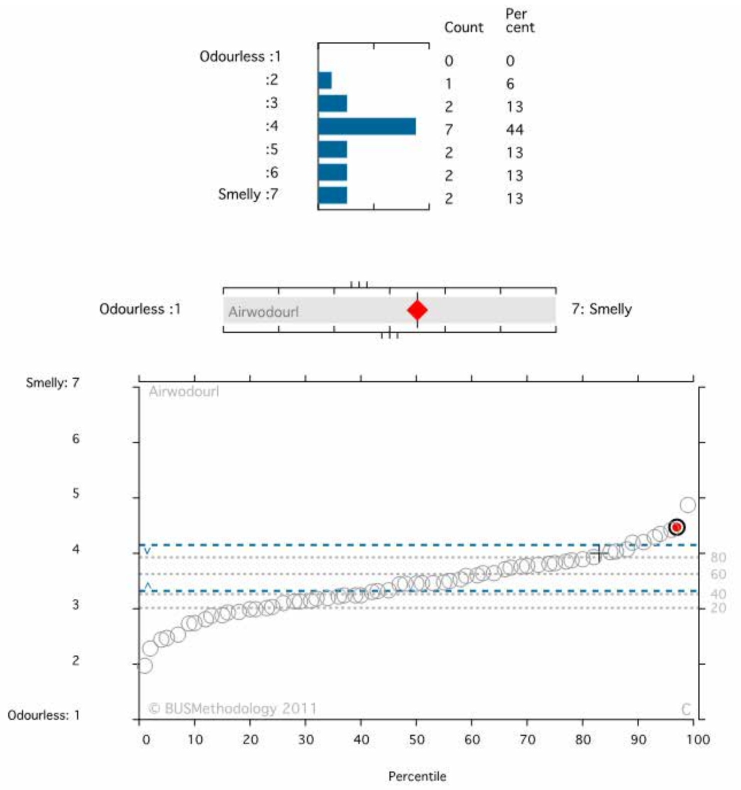
Air in Winter
There is a similar observation for the air in winter were the specific air quality issues score below the benchmark but the overall score is above. Here the School scored badly on the air in winter being smelly and still. From the monitoring work the Teaching Cluster mechanical ventilation flow was found to be low leading to rapid rise in CO_2 concentrations until the windows and roof lights were used to arrest the rise.

Control over Heating/Ventilation/Lighting
The control of heating was above the benchmark but near the mid-point so neutral with only 20% of respondents citing that control over heating was important to them. Control over ventilation and lighting scored well above the national benchmark.

Air Odour in Summer & Winter

Odour of air was scored poorer than the benchmark in both summer and winter(the benchmark tends toward a response that respondents usually find buildings neutral to odourless). As can be seen in Figure 79 Occupant Response – Air Odour in Winter, the spread of responses from previously surveyed building in the database is tight. This also corresponded to the occupants' response of the air being 'still' in both seasons. The teaching spaces have the ability for rapid ventilation with roof lights and patio doors so the comments suggest that these were not being used. Understandable in winter but surprising in summer.

Figure 79 Occupant Response – Air Odour in Winter



7.4.1 Key points from the BUS survey

The BUS performance indices show the building is in the upper part of the dataset for overall satisfaction and comfort. There are clearly some significant issues on comfort e.g. Cluster 4 overheating, but the design and the site location have instilled a high level of forgiveness from those people surveyed.

The architectural design is liked by the occupants but its spacious and sprawling arrangement has attracted some criticism of the length of communication routes.

The building scores poorer than the national benchmarks on dryness of air in summer with goes against a general trend found in buildings where outside air moisture content actually increases in summer and excessive humidity is often the problem. This might be allied to another poor scoring parameter which is the feeling of a lack of air movement and odours.

The building scores well for its utilisation of natural light but there is some implied criticism of the amount of artificial light which scores lower than the benchmark. However control of lighting is liked scoring at the 91st percentile of the dataset.

Noise from other spaces is also picked up as being an issue where it was rated poorly at the 5th percentile in the data set.

- Overall the BUS Summary Index was found to be 93 and in the top quintile indicating overall great satisfaction with the building, see Figure 77.
- There were significant complaints about the defects that were evident following handover yet the respondents demonstrated a ‘forgiveness’ because of other features of the design.
- Much of this can be attributed to satisfaction with the design which scores highly.
- There is high satisfaction with the facilities and the cleanliness
- Overall there is satisfaction with the combined comfort
- There is satisfaction with the winter temperature in winter although the report on temperature indicates it is slightly too cool
- Points which need further clarification are the results for air in winter dryness and control over cooling in summer. The satisfaction with the building is high on the 93rd percentile. The Satisfaction Index is derived from the scores for the building design, needs health and productivity, see Figure 77.

8 Details of aftercare, operation, maintenance & management

The maintenance and operational aspects of this project need to be disentangled from the defects which affected the building immediately after practical completion and are currently being dealt with. If one looks at the provision made for maintenance there are key omissions:

- Rainwater harvesting
- Heat pump controls
- Cluster 4 plant controls

It is not clear if the O&M roles and responsibilities were fully defined and whether funds were made available from DCC to cover some of the more advanced technologies. For a design of this type to deliver on its performance, it must be monitored and managed. The design does not use 'fit and forget' type technologies and they need attention to stay operating at their optimum. When performance drifts in a low energy design of this type the percentage variations are large because the absolute energy is small.

It seems that a lot of the responsibility for operation and management fell on the shoulders of the school caretaker. There are questions whether he had the time, amongst his other duties, and training to take the role on. The result was that a sophisticated building of this type was running with little management and omissions on the maintenance provisions.

8.1 Current O&M Arrangements

Maintenance of building and systems has been set up but mainly addresses the conventional elements of the building design. It is carried out on a two tier arrangement:

- Cluster 4 Central Boiler Plant maintenance is arranged through sub-contractors appointed by Devon County Council (DCC). This would deal with the significant mechanical plant items on a twice yearly basis – i.e. boilers and pumps.
- Maintenance of other systems and building is by sub-contractors appointed by the School

The School has a maintenance contract with Sherwood M&E Contractors who for following:

- Kitchen hoods and ventilation systems – twice a year
- Kitchen Hood degrease 3 times a year
- Heat pumps – once a year
- Reactive maintenance on M&E services

Specialist contractors are employed by the school for:

- Tyco for sprinklers
- Trinity for fire and security systems
- Interserve for major building fabric works

8.2 Conclusions and key findings for this section

The School are satisfied with the O&M arrangement they have in place and particularly their relationship with Sherwoods who provide a ‘one stop shop’ service for most of the routine and reactive maintenance items. In this arrangement there are omissions that have a major impact on the performance of the school.

A significant omission from the services is that for the controls. The Trend controller in the cluster 4 boiler plant and space temperature controls in the teaching clusters are not routinely maintained. These are critical systems in running the building to its optimum and will be taken up with the School to put something in place which is effective and affordable.

Although there is provision in the fixed metering system to collect energy data this is currently not used in a systematic way in energy management of the School. This will be another area where we will work with the school to utilise this data to improve the buildings operation.

Primary schools have at best a single caretaker who normally has a wide range of other duties in addition to running the building services. The buildings systems should therefore be:

- Simple but capable of being managed and controlled centrally, e.g lighting, global signals on the BMS’s control of space heating
- have a maintenance contract with full after care and training for at least 2 years
- have appropriate controls
- adequate training should be given on how to carry out day to day operation.

The local authority maintenance department should review and sign off the proposals, including any VE changes that will have a substantial impact on how the school will operate after handover.

9 Technical Issues

9.1 Emerging Issues with the Building and its Systems

Over the period of building monitoring the following issues have emerged with both the building and its services

- Overheating
- Water ingress through the timber structure
- Manuals and teaching staff how to use systems
- Commissioning issues, defects, controls
- Remote monitoring of systems
- Teaching Clusters time-switch control and space thermostat locations
- Cluster 4 Control improvements of the central boiler plant
- Heat pumps failures
- Failures with lighting control systems
- Problems with the rainwater recycling cisterns

9.2 Conclusions and key findings for this section

There are issues with the building fabric which are a cause for concern and are currently being investigated by DCC. These being the leaking flat roofs and water penetration through the timber structure.

The control of systems is a major issue in particular the omission of time-switch control of the heat pumps in the Teaching Clusters and the control main boiler plant which are showing excessive energy use. These will be addressed with the school to rectify the problems with affordable and practical solutions.

Energy management is not high on the Schools agenda and this is an important area to be accommodated in the School’s management structure and be matched to its technical resources.

An action plan to improve the buildings performance has emerged from the monitoring work. This has been discussed with the School to get these affordable and effective measures implemented as soon as possible:

7. Heat pump controls - the machines are showing continuous operation in cold weather. The Nibe SMO 10 controller has the facility to operate in a set-back mode and to accommodate vacation periods.

8. Review the time schedule controlling the kitchen AHU and extract fan which appears to be on continuously.

9. Re-location and securing of the teaching space thermostats that are in the receipt of cold outside air from external glass access doors which gives a false reading and in some cases are at a height where they can be adjusted by the children.

10. Cluster 4 suffers from complaints of overheating which is borne out from our space temperature monitoring. The Trend controller needs to be re-commissioned in order to revert back to a set-back to of say 17°C rather than the current set point of 20°C when the building is unoccupied. There are also issues with the run hours of the AHU units in cluster 4 which are running when the building is unoccupied which could benefit from are review of time switch settings

11. Energy management – there is a good provision of metering in the electrical distribution system with a communications network back to the Schneider 3500 controller - however this is not being used effectively. Monitoring and targeting software can be applied in order that a tighter rein can be kept on energy use and waste identified and corrective action be put in place. The plan is to incorporate both gas and water metering to this monitoring network.

10 Key messages for the client, owner and occupier

10.1 Energy Performance

The energy use of the school compares reasonably well with TM46 benchmarks but it is not realising its potential as an exemplar low energy building. The electricity use is higher than the benchmark because of the application of air source heat pumps in the Teaching Clusters and as a consequence gas usage is lower than indicated in the benchmarks.

The School could perform better - the principal areas of concern are the control of heat pumps which lack any time switching, control of heating systems serving Cluster 4 and leading to overheating of certain spaces.

A good story to emerge from the first years monitoring is the performance of lighting and small power in the teaching clusters. Lighting has been recorded at 7.4kWh/m2 which is unusually low and is being checked with portable power profilers to verify this data. Small power use is also low at 2.0 kWh/m^2 reflecting the low utilisation of powered equipment particularly in the teaching spaces.

10.2 CO_2 Emissions

The renewable energy sources have had an impact upon the resultant CO_2 emissions of the School. The current performance of the school puts it at a C rating for its DEC. With better control and scheduling of the existing HVAC systems the School could be operating at a B rating. These measures are detailed in this report are low cost and can be readily implemented.

10.3 Energy Management

Another critical area is the energy management of School. There is a reasonable level of sub-metering of provided in the original design. The information is not being used to effectively manage the performance of the school. There needs to be a system of reporting against benchmarks that can be reviewed by the School to identify any waste to save energy, carbon and indeed cost to the School. This will need to be automatically collected and collated as the staff have very little time to spend analysing raw data.

Staff training and awareness of the building and how it should be controlled needs to be addressed. A management system of checks on the ‘vital signs’ of the systems could be put in place to identify energy waste. This would need to be set up so that it involved minimum time of the staff but should be effective in identifying waste. This could be realised using the sub-metering data that is recorded on Schneider EXG data hub and from which the School currently collate data. Ideally this could be put on to a dashboard to indicate a green amber or red status on the services to inform the staff that corrective action should be taken.

10.4 Occupant Satisfaction

The School scored well in the BUS occupant satisfaction survey, lying in the top 10% of buildings in the national database. As always there were complaints - noise emanating from inside the building was cited and Cluster 4 overheating. The light airy design however was well received which introduced a degree of forgiveness amongst respondents for other building problems.

The fabric problems which have emerged since occupancy – water ingress on flat roofs and water penetration of the timber structure. These are currently being investigated by DCC and remedial works will follow.

11 Wider lessons

The design of the School gave it the potential to be exemplar both in terms of its architecture and performance in use. The design intent has succeeded in many of its aspirations in that there is a high level of satisfaction with the people who use it. However the performance evaluation project has shown that it is not realising its full potential for easily rectified problems with the services. In addition the problems of leakage and rot found in the building fabric are niggling problems letting a good design down.

The important point with high performing buildings is they are not using ‘fit and forget’ type technology particularly where there are people involved in the process. A building can be optimised to run at its best but it must be kept there by effective management – it can easily deteriorate and lead to poor environmental conditions and high energy use.

Management of the school is the critical factor. In larger commercial buildings using similar technology there is usually an engineering FM team to deal with these issues. At school level there is not that luxury - it’s normally the caretaker and the teaching staff who have responsibility for the running of their buildings and services. These will be generally non-technical people who have many other responsibilities in the running of the school so building performance is last on the list and only addressed when it’s a major issue, e.g total loss of heating.

There is a duty of care of designers to not introduce unmanageable complexity so there must be provision in the design to facilitate management. It can be argued, quiet correctly, that the provision of the sub-metering system with the Schneider EXG was sufficient for effective management to be exercised. However the interface with the School staff is crucial and in this instance it required the BPE team to set up a reporting spread-sheet so that the data could be collected for the monitoring project and could in the future be used for managing the operation of the School’s systems.

The computing power of BMS technology, commonplace in large commercial buildings, is now flowing down into small commercial buildings and schools but for these to be used effectively the interface is key. A dashboard type approach is the way forward to show clearly how the School is performing against benchmarks and alert staff to conditions that require attention. The dashboard designs now being applied have not got the complexity of a large commercial BMS head end. They are understandable relating the vital signs of a building and its systems in an accessible way. The dashboard should allow effective management to be carried out reporting weekly of energy use against benchmarks, identifying incorrect scheduling and control of plant and equipment.

Looking to the future of how we keep good buildings from going bad, particularly in small and medium sized non-domestic buildings, we can utilise the computing power for control and management but we need to get the interfaces right. If we do so the building will in all probability stay on track once the design and BPE team have left the scene.

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Appendices

Appendix A Description of Building Services

The principal building services are described in section 3.0, the remainder are discussed here.

A.1 Cluster 4 Heating System

Within Cluster 4 underfloor heating provides the primary heating for the main hall, music room and changing areas. Radiators provide heating to the administration and kitchen areas.

Cluster 4 is served by two 65kW gas-fired condensing boilers providing low temperature hot water serving the new heating element throughout the Cluster. Boilers are operated at 80°C flow/60°C return. Each boiler is complete with modulating pre-mix burner a control pack providing the control system with the facility to enable, control and monitor fault indication.

The amount of heat generated by the boilers is dictated directly by the mechanical control panel to suit external weather conditions, local space conditions are controlled by thermostats or thermostatic radiator valves. There are four secondary circuits;

- An 80°C/60°C variable volume, constant temperature circuit serves the air handling unit and duct mounted heater batteries.
- An 80°C/60°C constant volume, constant temperature circuit serves the domestic hot water calorifier
- An 80°C/60°C weather compensated, variable volume, variable temperature circuit serves all radiators
- 50°C/30°C weather compensated, variable volume, variable temperature circuit serves all underfloor heating manifolds.

A.2 Cluster 4 Mechanical Ventilation

Ventilation to the offices is achieved by natural ventilation via openable windows.

Low-level attenuated louvre and high-level openable windows provide ventilation to the sports hall. Ventilation to the changing rooms is achieved by using a roof mounted mechanical ventilation unit with heat recovery; supply air is ducted to the space. Air is extracted from the changing rooms and toilets via high level ductwork complete with surface mounted grilles. This air is ducted back to the ventilation unit and exhausted to the atmosphere.

Extract ventilation to the caretaker's kitchenette, community kitchenette and adjacent WC is achieved via a roof mounted extract fan.

A heat recovery unit housing two fans and a plate heat exchanger is located in the music room store. Fresh air is ducted from the roof via the plate heat exchanger and delivered to the music room by three manually adjusted jet diffusers. Return air passes from the space back to the ventilation unit, The air then passes through the heat exchanger before being exhausted above the roof. The heat recovery units will run whenever the mechanical ventilation is operational; the ventilation is time controlled to provide fresh air during the operational hours of the school.

A.2.1 Cluster 4 Kitchen Ventilation

Supply air is provided by an AHU located on the roof, which is ducted to grilles located within the kitchen ceiling. Air is extracted to the atmosphere via a roof mounted extract fan, connected via ductwork to the kitchen hood. This kitchen ventilation system is set to run between 8:00 and 15:00hrs on days when the school is occupied and is controlled by the BMS.

A.3 Low Voltage (LV) Electricity Distribution

The building is supplied from an LV three phase and neutral supply derived from the local supply authority. This enters the external feeder pillar from below ground and terminates in to the Regional Electricity Company (REC) owned main switch.

Supply cables are then taken from the main REC switch through an isolating switch. A cable is connected to the live incoming side of this isolator for the sprinkler equipment supplies, this terminates in to another fused lockable isolator to provide isolation and protection to the sprinkler feed cable. The outgoing side of the main isolator is then connected to the incoming side of the main panel, see Figure 64 which shows a simplified LV schematic and the location of permanent meters.

From the main panel supplies are provided to the various sub distribution boards and main isolators throughout the four buildings and ancillary buildings. Full details of the locations and the equipment that they feed can be found on the layout drawings, circuit test sheets and general schematics.

The main panel is an MCCB panel board providing both incoming and outgoing protection in the form of adjustable MCCB's.

A.4 Lighting systems

A.4.1 Internal lighting

The internal lighting schemes consist of the following arrangements:

- Classroom units: T5 fluorescent with day-light linking and PIR control
- Staff room and offices: T5 fluorescent with day-light linking and PIR control
- Toilets: PIR control

A.4.2 External Lighting

The external lighting is served with compact fluorescents controlled by photocell and time switch control at 22.00hrs off overnight.

A.4.3 Kitchen

The kitchen in cluster 4 operates 5 days a week producing 150 to 250 meals a day serving Dartington School Breakfast Club, Bridge Learning Centre, and Bidwell School serving 16 meals.

The kitchen uses gas cooking and is fitted with the following equipment:

2 No commercial size freezers	Peeling m/c
Food Mixer	2 No Steam Ovens
Dishwasher	Washing m/c

Mechanically ventilated with supply and extract

A.5 Small Power

Small power in the Teaching clusters is mainly used for audio-visual for classrooms, whiteboards, and cleaning equipment

A.6 Computer Equipment Room

The School has a small server with associated DX cooling system. A DX Split system provides cooling to the server room. The condenser is located on the Cluster 4 plant room roof. The internal evaporator is mounted above the server room door.

A.7 Cluster 4 Control Setting

Cluster 4 is served by a 'mini' BMS system - Trend IQA View 4 Touch Screen Panel located in boiler room. Plant is set to reach temperature at 06.45hrs with optimiser. The Trend Controller was interrogated establish control settings, the table below summarises the controls settings recorded in July 2011

Table 15 Cluster 4 Trend Controller Settings

Variable	Settings	Comments
HWS Time schedule	08.00-15.00hrs	
Kitchen Vent	08.00 -15.00hrs	
Changing Rooms	06.45- 16.00hrs	
UF/VT Occupancy	All day	
VV Occ Schedule	06.45 – 16.30hrs	
1st Stage frost SPA	3°C	Set point adjust
2nd Stage frost SPA	5°C	Set point adjust
3rd Stage frost SPA	10°C	Set point adjust
Boiler flow	73.67°C	Monitored
Boiler return	72°C	Monitored
CHW Tank Band	1°C	
Booster Tank temp	21.29°C	Monitored
Electric Total Count	30,275kWh	
Gas Total Count	49.1m3	
High Outside temp SPA	19°C	Set point adjust

Variable	Settings	Comments
HWS calorifier	57.22°C	
HWS SPA	65°C	
Music room SPA	21°C	Set point adjust
Outside Air	23.59°C	
Plantroom Water –this month	4.3m3	Metering
Plantroom Water –this week	2.5m3	Metering
Plantroom Water –today	2.5m3	Metering
Water total count	913.02m3	Metering
Under floor (UF) VT Calc	34°C	
UF VT temp	24.93°C	
UF VT max flow	35°C	
UF VT min flow	34°C	
UF VT SPA	21°C	Set point adjust
UF VT Space temp	25.01°C	Monitored
UF VT Warm-up	360mins	
Variable Temperature (VT) Calc	20°C	
VT Flow	25.81°C	
VT max flow	75°C	
VT min flow	20°C	
VT Occ SPA	21°C	Set point adjust
VT Space temp	25.50°C	
VT warm up SPA	360mins	Set point adjust

Appendix B: Heat Pump Performance Data

The performance of the air to water heat pumps is discussed in Section 3.2. This Appendix gives supporting data that was collected from other Teaching Cluster 3 systems.

B.1 Cluster 3 Heat Pumps and Flow Boilers

B1.1 Heat Pump (a)

During the measured period, heat pump (a) has an almost constant varying load throughout the day and night, with occasional zero loading periods for approximately 2-6 hours every few days. The peak loading is 2.95kWh on 26/01/2012, see Figure 80 .

Figure 81 shows the daily loading pattern which shows that the heat pumps are left on at night. Reducing this night time loading period would decrease the power consumption of the heat pump..

Figure 80 Cluster 3 Heat Pump (a) Power Demand for the Period 26/01/2012 - 04/04/2012

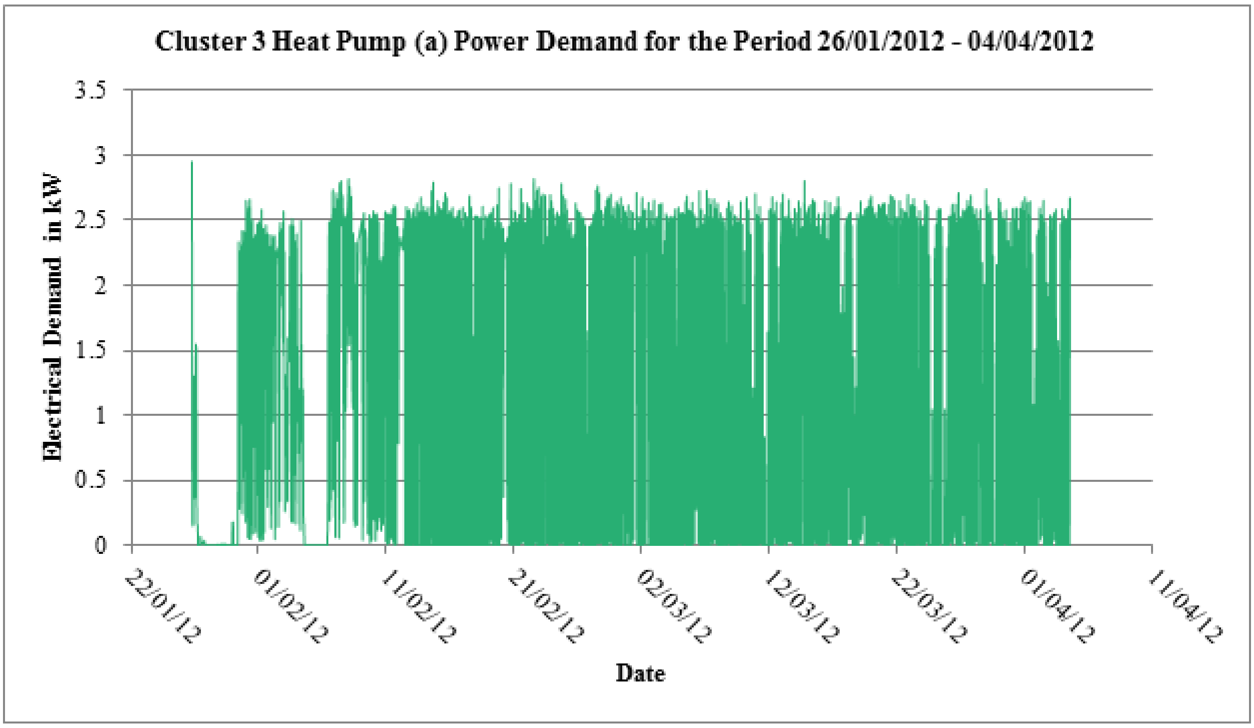
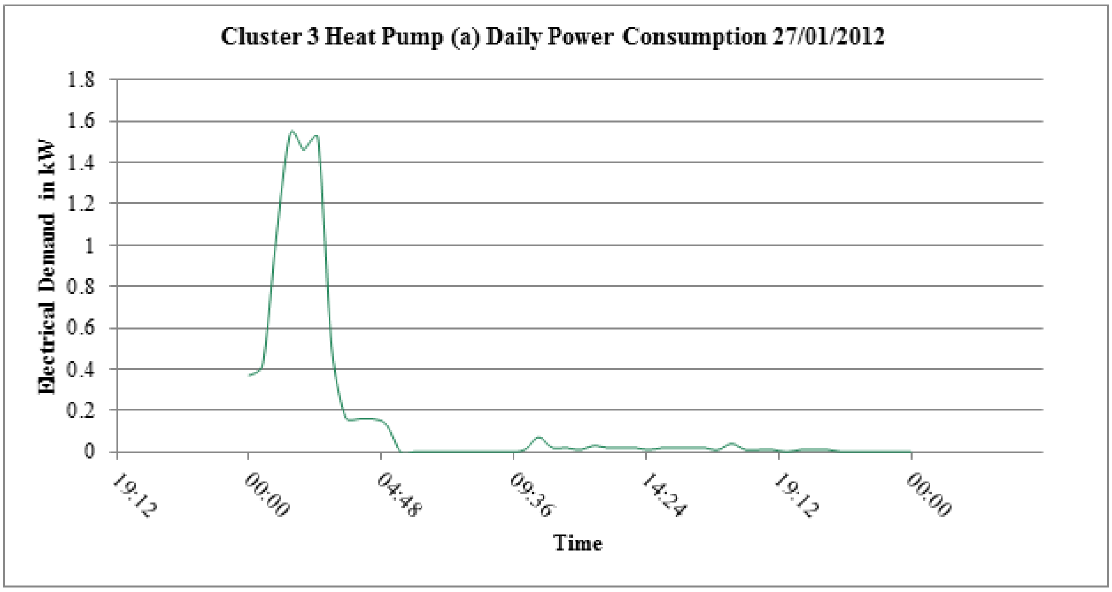


Figure 81 Cluster 3 Heat Pump (a) Daily Power Consumption 27/01/2012



B.1.2 Heat Pump (b)

During the measured period, heat pump (b) has an almost constant varying load throughout the day and night, with occasional zero loading periods for approximately 2hours every few days.

Figure 83 shows the daily loading pattern which again show the heat pumps are operating continuously. There is a cyclic pattern in the daily profile which indicates a 2 hour run, 1 hour off pattern

Figure 82 Cluster 3 Heat Pump (b) Power Demand for the Period 26/01/2012 - 04/04/2012

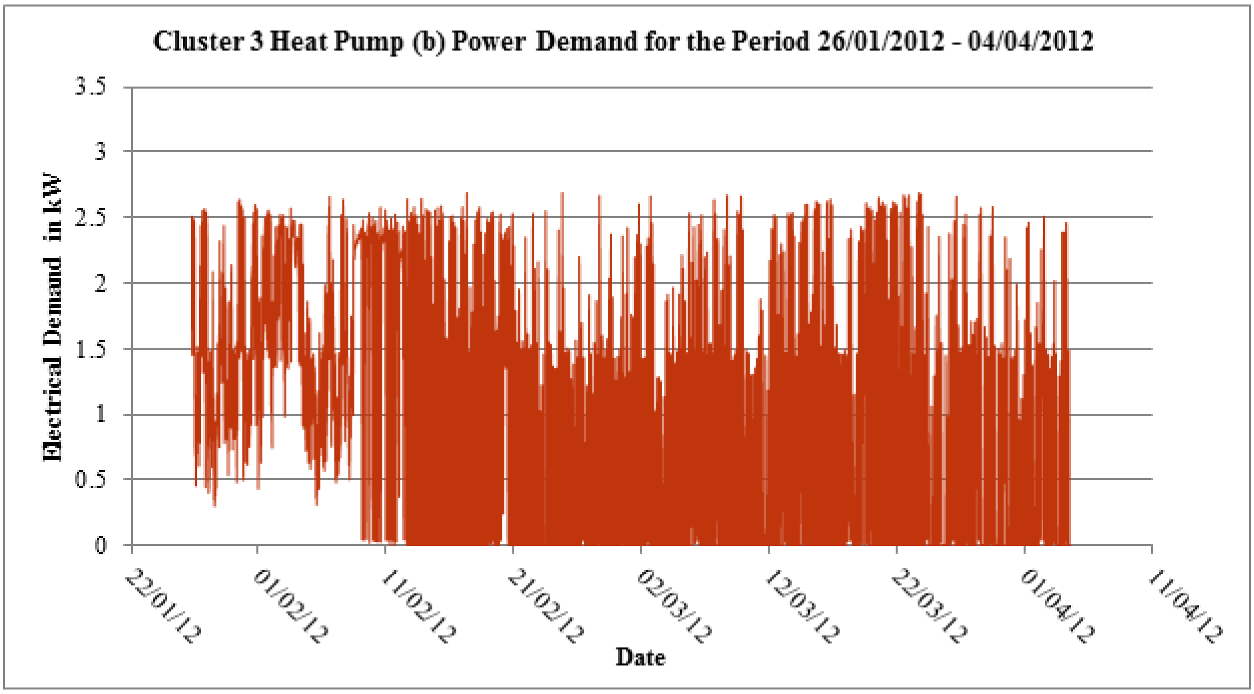
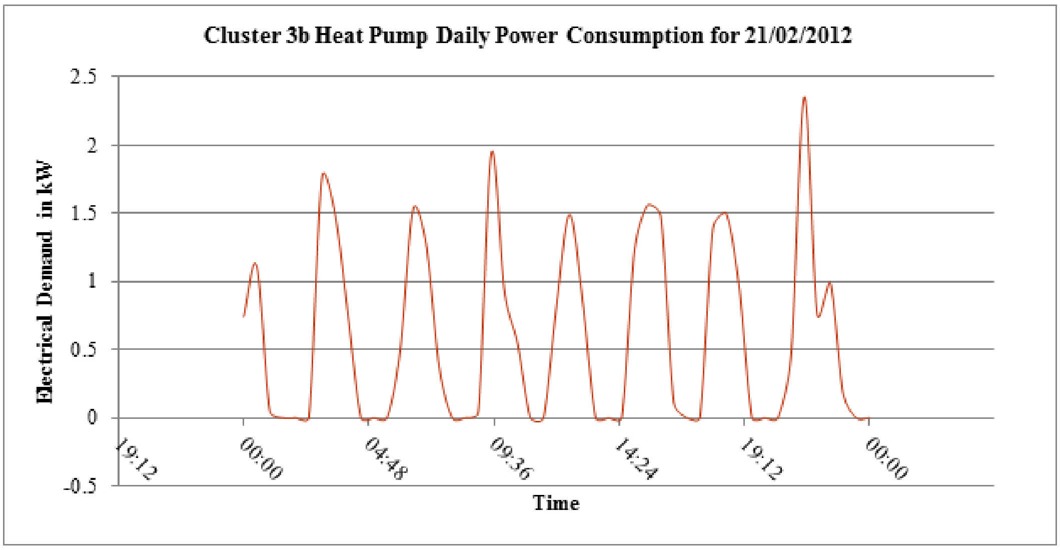


Figure 83 Cluster 3 Heat Pump (b) Daily Power Consumption for 21/02/2012



B.2 Cluster 3 Flow Boiler

The Cluster 3 flow boiler power profiles show that there is mostly zero loading with a few periods of intermittent loading. During these periods of loading, the flow boiler appears to be running with a varying load throughout the day and night as shown in

Figure 85. After 21/02/2012 and once into the milder weather there is no loading, which is similar to the power profile of the flow boiler in Cluster 2. The peak loading was 1.6kWh on 26/01/2012, which is the same day as the peak loading from the flow boiler in Cluster 2.

Figure 84 Cluster 3 Flow Boiler (a) Power Demand for the period 26/01/2012 - 04/04/2012

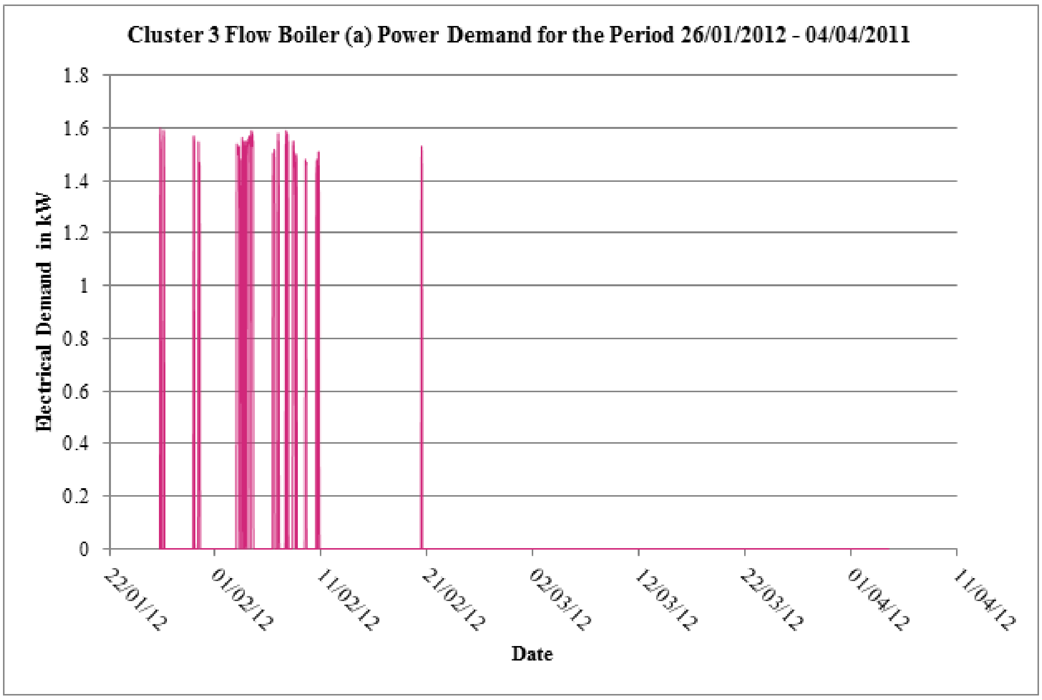
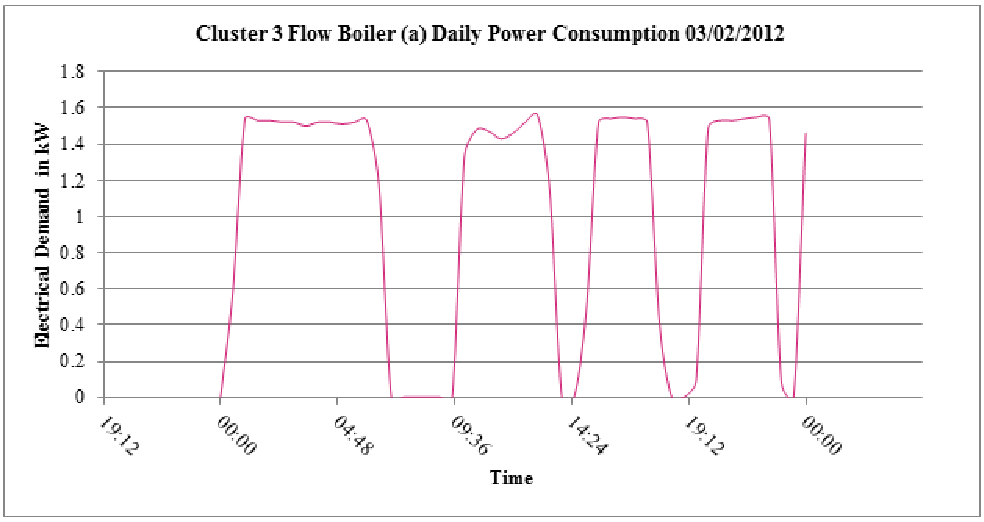


Figure 85 Cluster 3 Flow Boiler (a) Daily Power Consumption 03/02/2012



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Appendix C: Occupant Survey Results

See attached files

Appendix D: Save It Campaign

D.1 School engagement with Building Performance Team – Save it Campaign

In order to engage with the main users of the School, a ‘Save-It’ campaign was run by the BPE team. The Save It Campaign Workshop was run on 12th March 2013 with three classes from Years 5 & 6. The children took part in an interactive presentation about different aspects of sustainable building design including sustainable building materials, green roofs, renewable energy production, energy saving lighting controls, rainwater harvesting and natural ventilation. The children were then split into teams to design a building focussing on making it as sustainable as possible whilst still thinking about the use of the building and the appropriateness of their solutions. The workshop materials have been made available to the school to repeat the workshop if they wish.

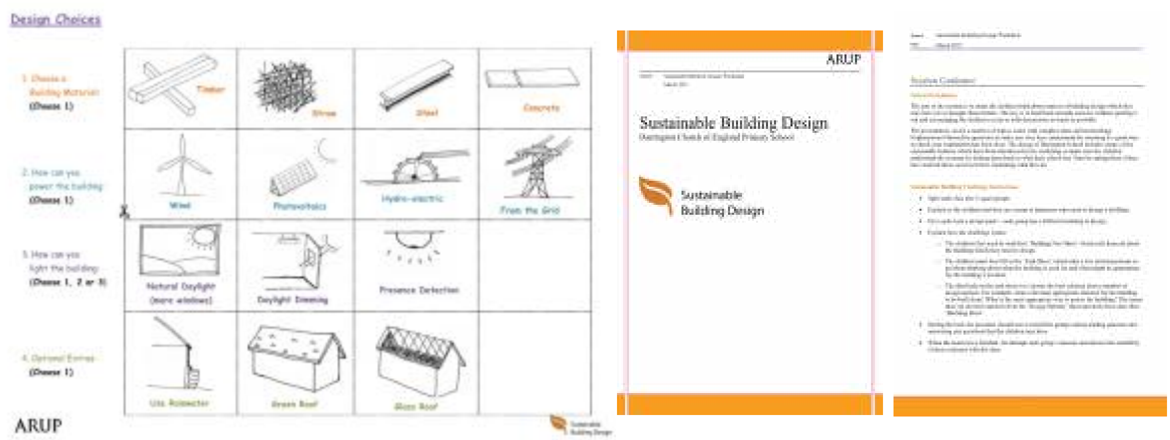


Figure 86 Workshop Material for the Sustainable Building design Workshop

The following feedback was received from the Headteacher regarding the Save-It Campaign workshop:

“*We were so pleased with this input to the children which fitted exactly with the way the school has wanted to work; it was well planned to link with children's learning encouraging their connections to core subjects (literacy, maths and science), planned ahead of time so that teachers were well prepared and had a real life link. We managed to make further connections with students from Plymouth Uni who wanted to learn about how our building is sustainable and some of the pupils were able to meet and share their understanding.*

Having a range of audiences has also been inspiring for the children.”

D.1 School engagement materials on energy and water management

A workshop named ‘Water for the World’ has been issued to the school with the Sustainable Building Design workshop as part of the Save-It Campaign initiative. This workshop, produced by Arup and Engineers Without Borders UK highlights the need to save water and explains the processes which water must go through from reservoir to tap. It also links International Development and highlights the need for filtering and treatment to prevent diseases. The workshop's practical element involves the children getting into teams and building simple filters from plastic bottles, stones, sand and charcoal.

Figure 87 Samples from the Water for the World Workshop

Appendix E: Thermographic Survey

A thermographic survey was carried out on the school to identify air leakage paths, cold bridges and to analyse he general thermal performance of the clusters.

Date: 07/01/2013	Time: 1100-1500
External dry bulb temp: 11.5°C	Wind; ~9mph/south
Relative humidity: 76%	Pressure 1024mb falling

External Walls

Figure 88 Cluster 3 East facing facade

Figure 89 Cluster 3 West Facing Facade

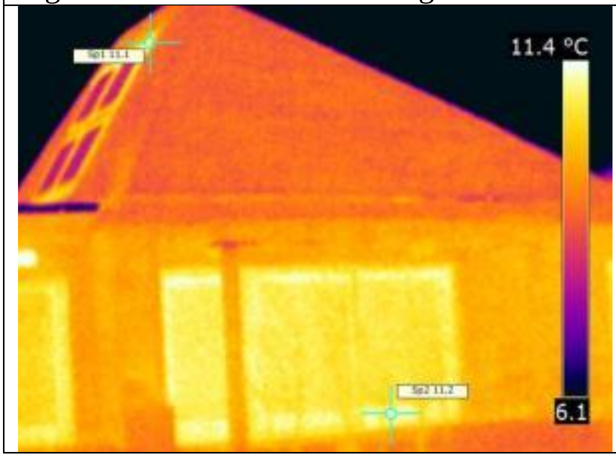


Figure 90 Cluster 3 Rear, West facing facade

Figure 91 Cluster 3 Rear, North facing facade

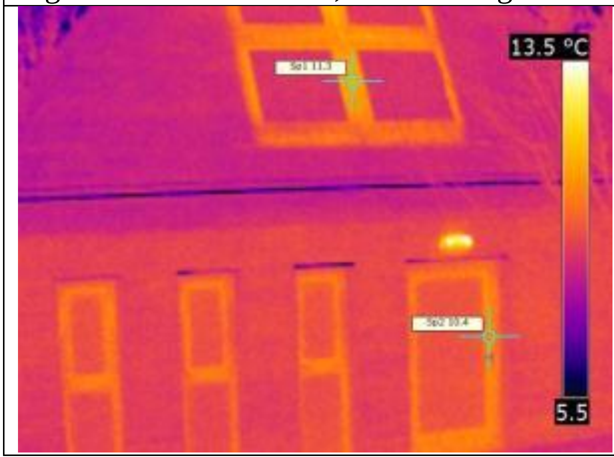


Figure 92 Cluster 3 Rear, East facing facade

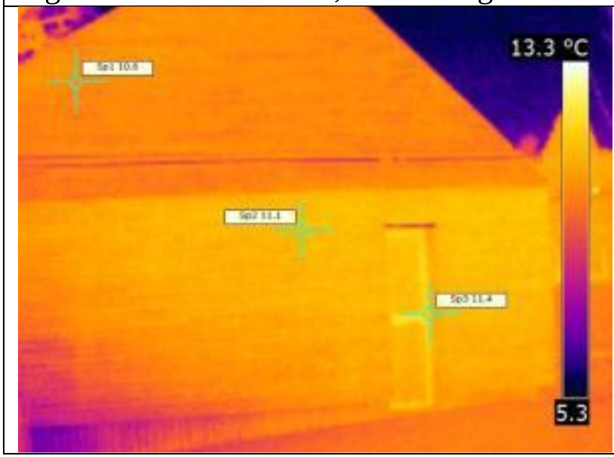


Figure 93 Cluster 2 East facing facade

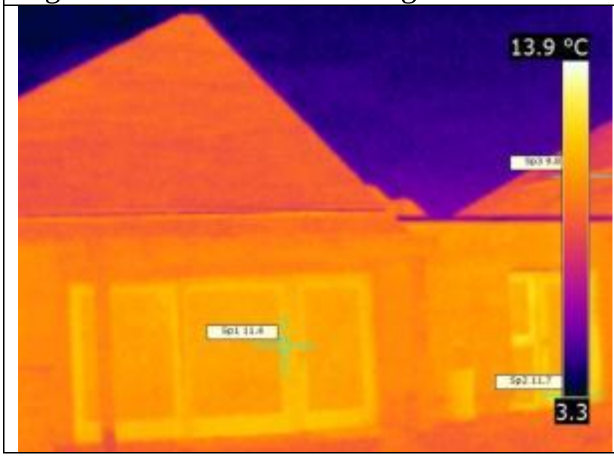


Figure 94 Cluster 2 South facing facade

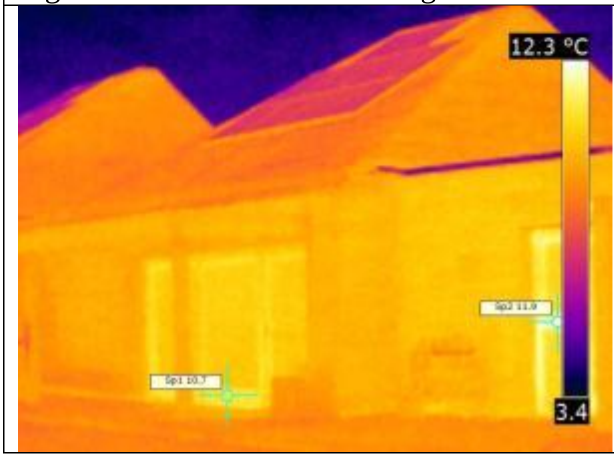


Figure 95 Cluster 1 East facing facade

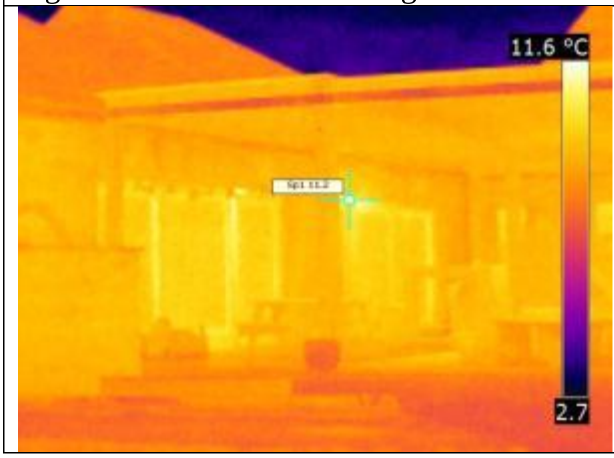


Figure 96 Cluster 4 North-West facing facade

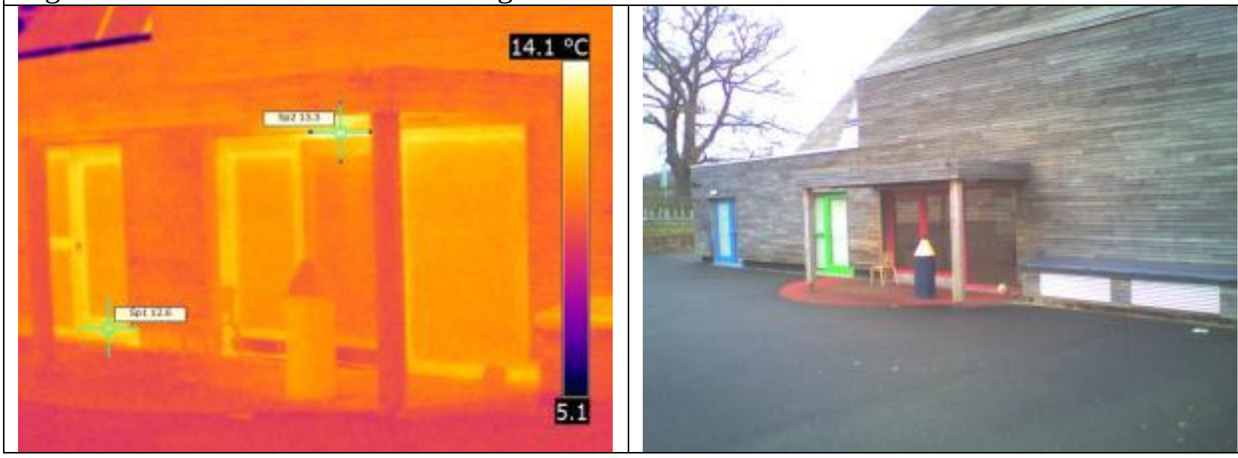


Figure 97 Cluster 4 North-West facing facade

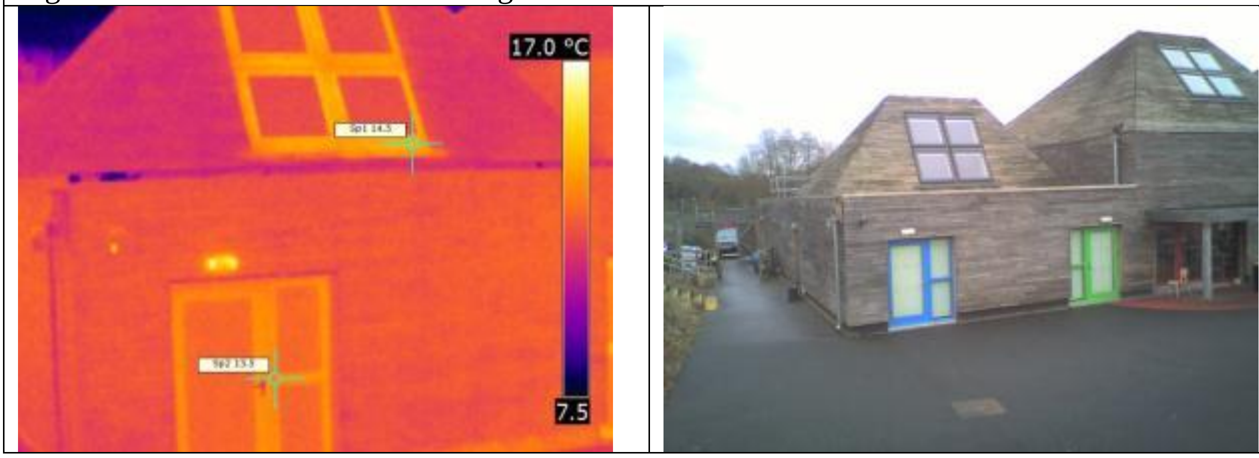


Figure 98 Cluster 4 North-East facing facade

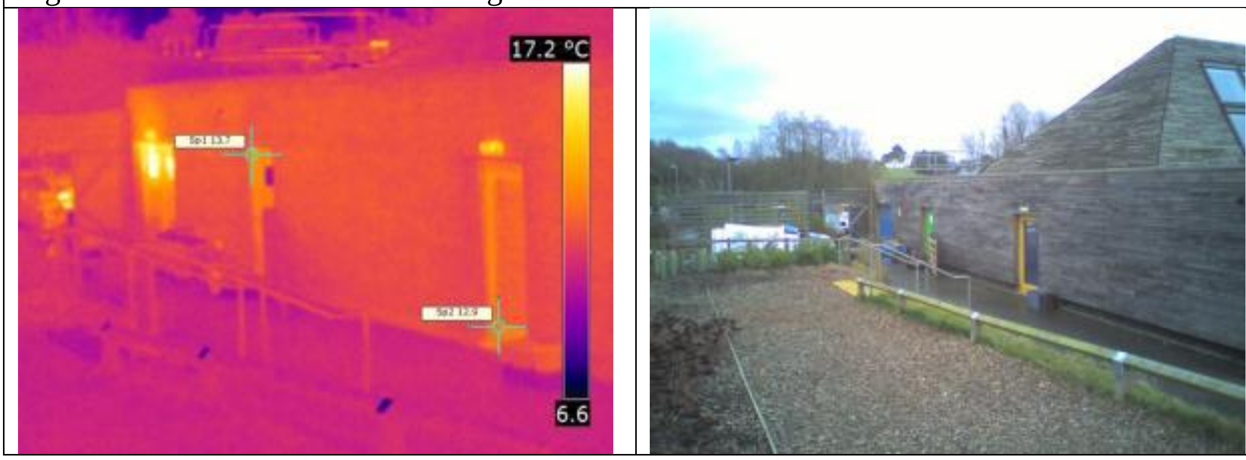


Figure 99 Cluster 4 South-East facing facade

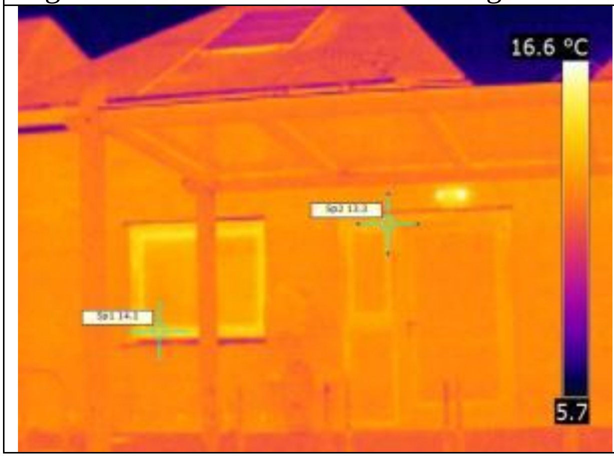


Figure 100 Cluster 4 North-East facing facade

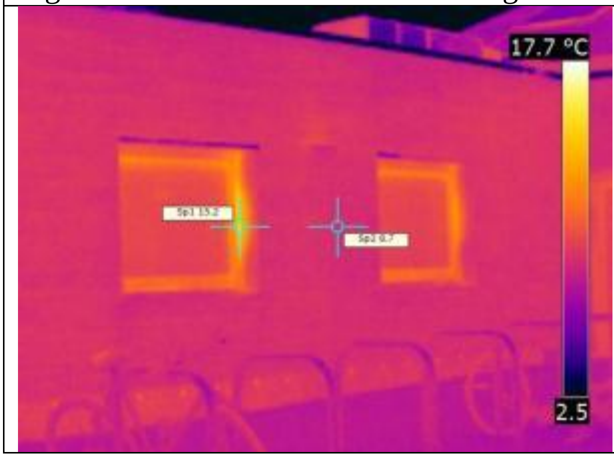


Figure 101 Cluster 1 Rear, North facing facade

Figure 102 Cluster 2 Rear, North facing facade

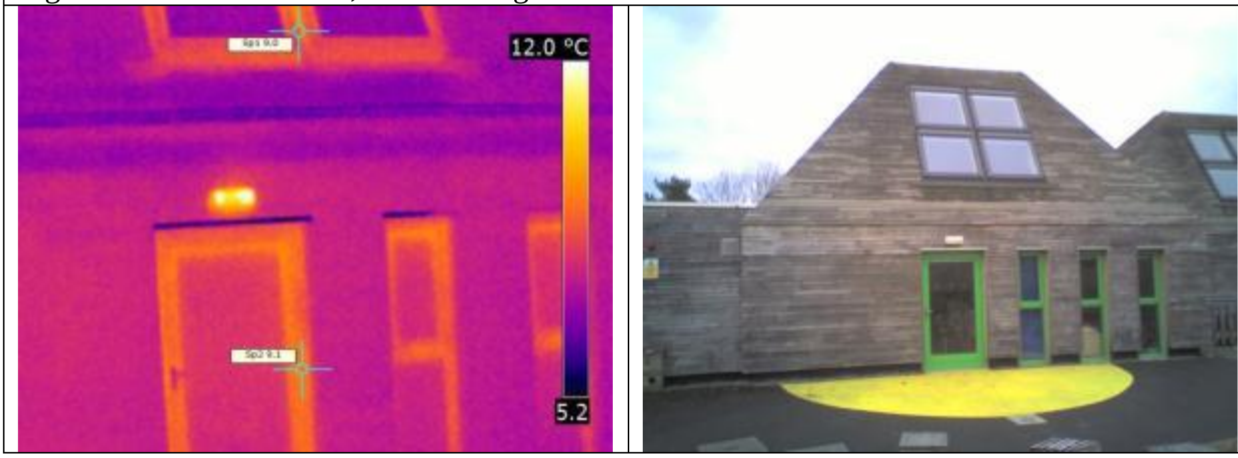
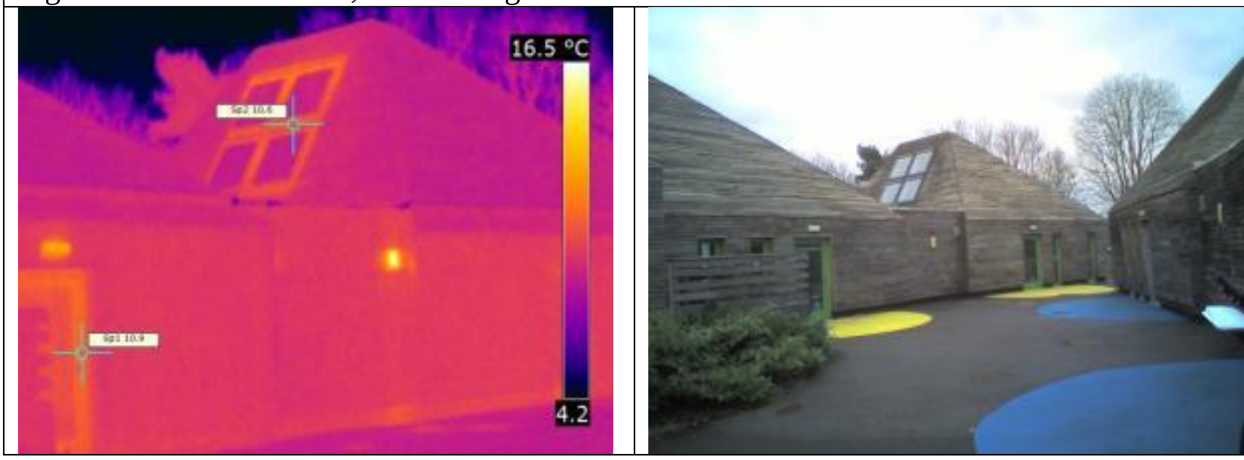


Figure 103 Cluster 2 Rear, West facing facade



Air Leakage Tests

Figure 104 Air Leakage Test 1, Cluster 1

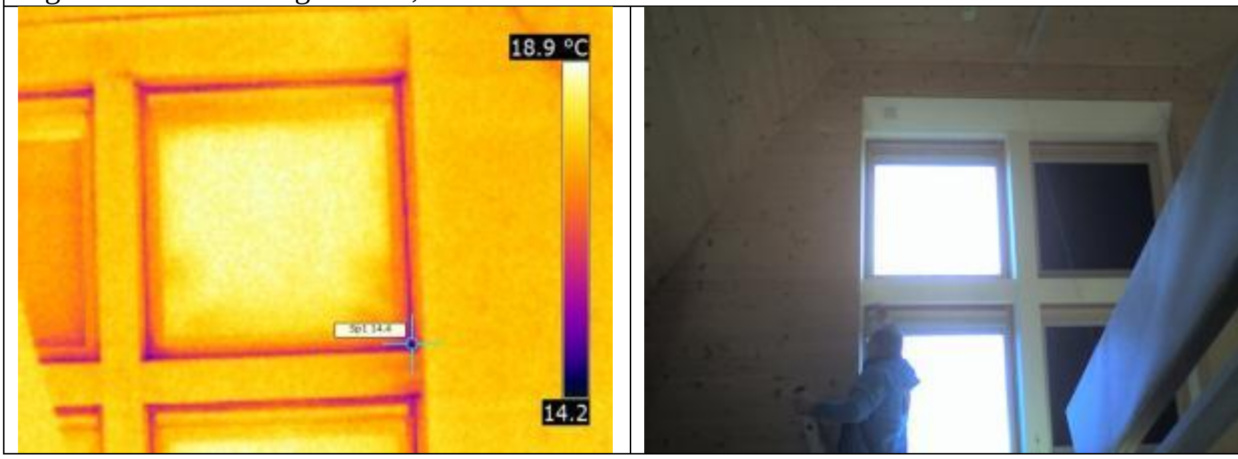


Figure 105 Air Leakage Test 1, Cluster 1

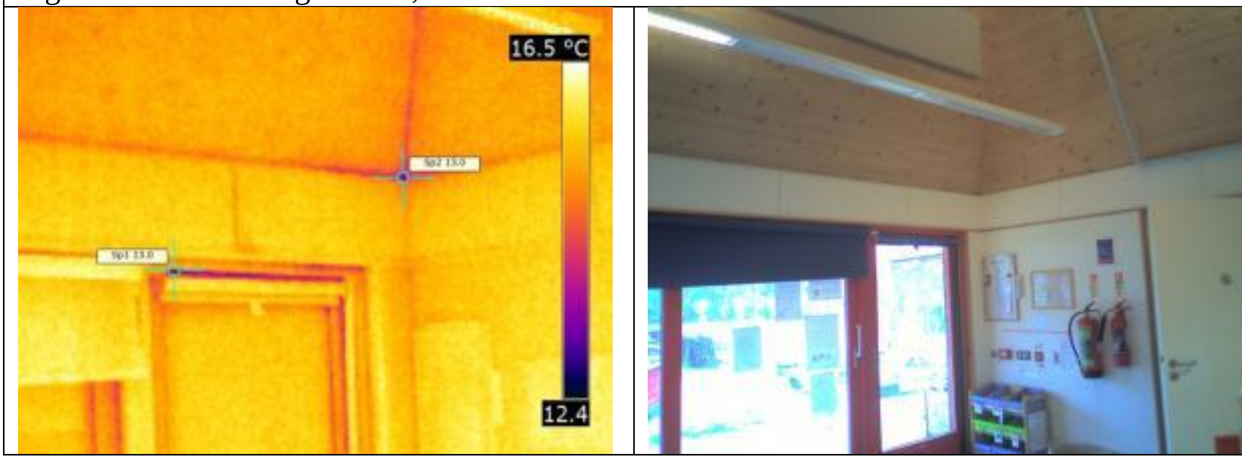


Figure 106 Air Leakage Test 1, Cluster 1

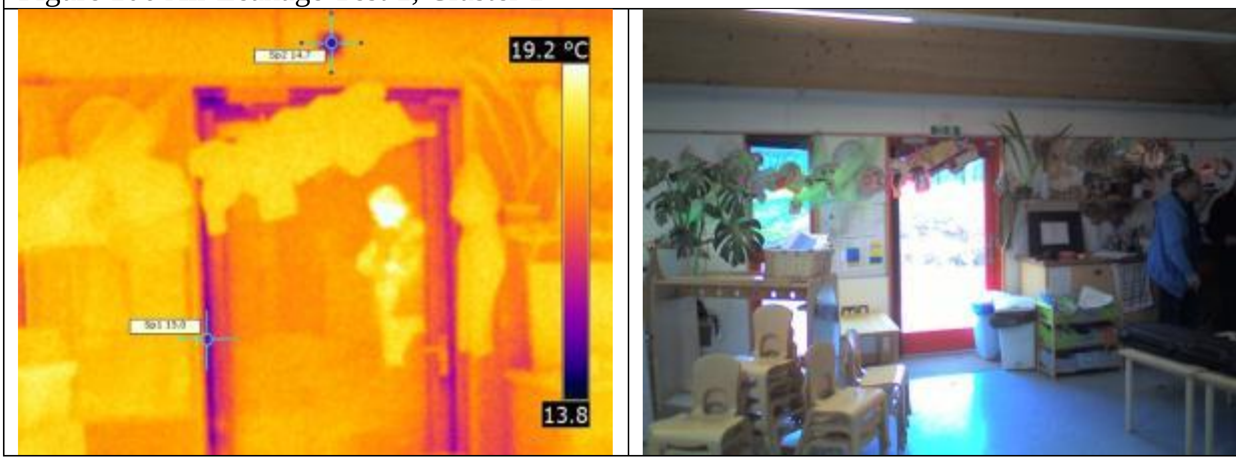
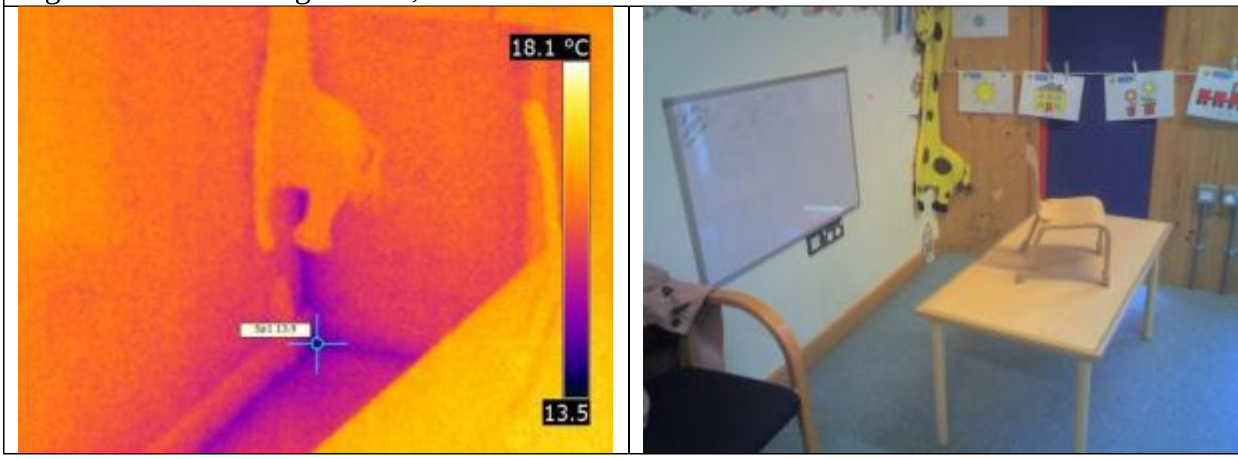


Figure 107 Air Leakage Test 1, Cluster 1



Test Area 2

Figure 108 Air Leakage Test 2, Cluster 1

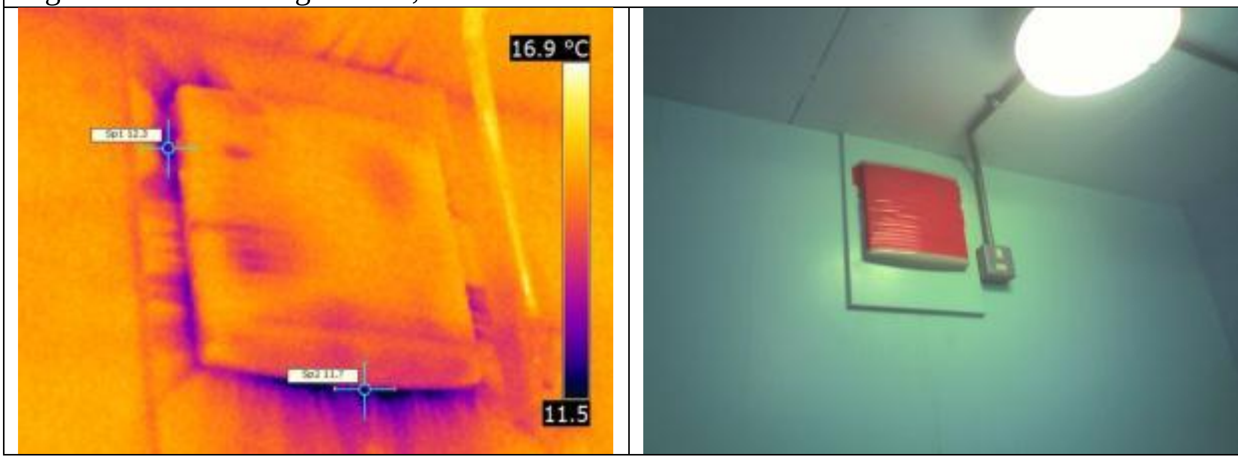


Figure 109 Air Leakage Test 2, Cluster 1

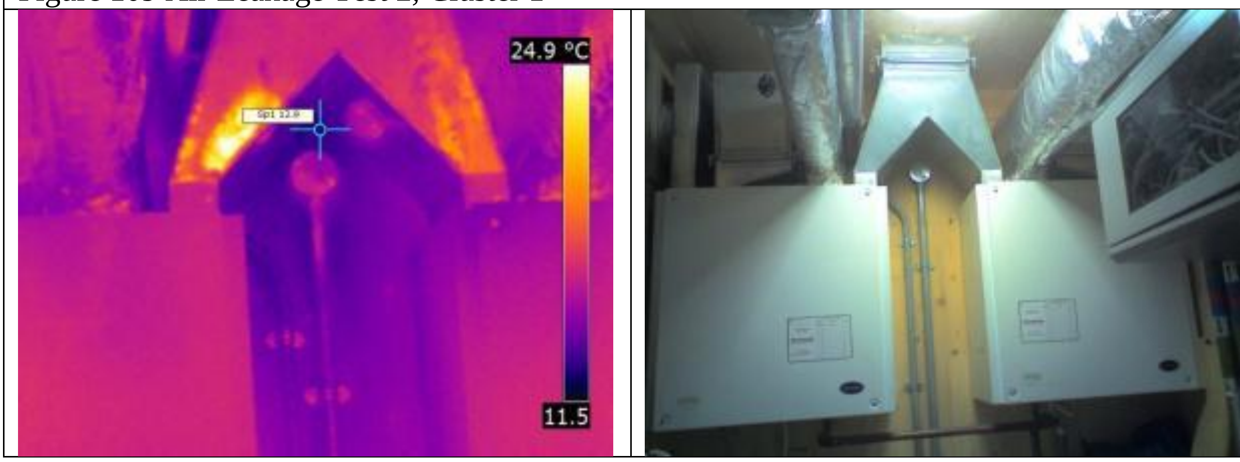


Figure 110 Air Leakage Test 2, Cluster 1

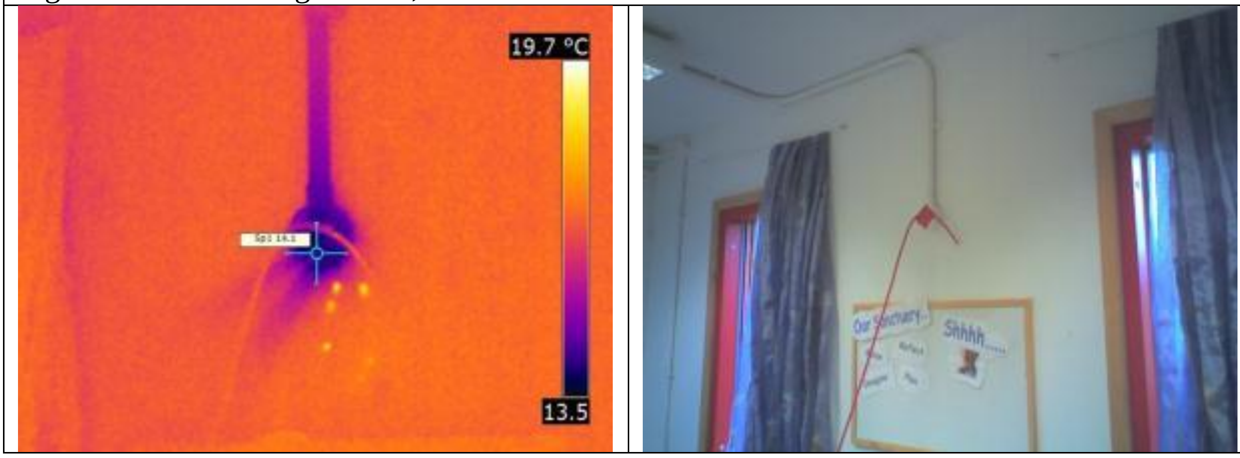
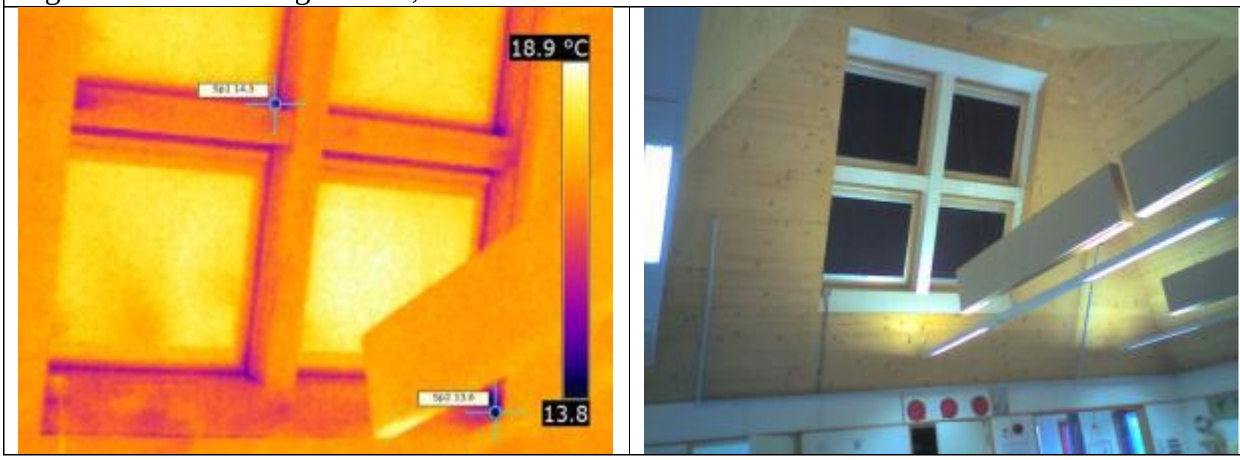


Figure 111 Air Leakage Test 2, Cluster 1



Test Area 3

Figure 112 Air Leakage Test 3, Cluster 2

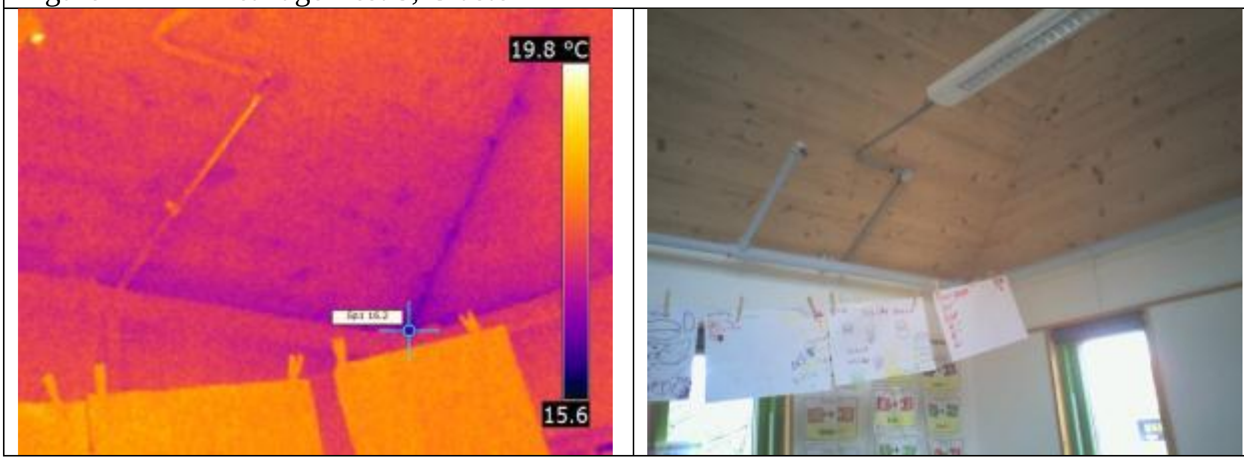


Figure 113 Air Leakage Test 3, Cluster 2

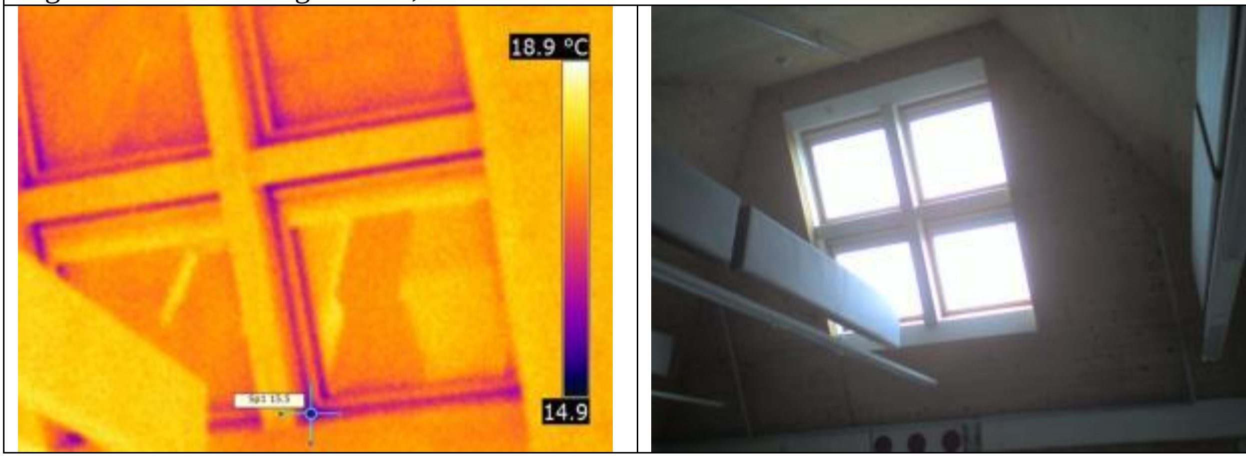


Figure 114 Air Leakage Test 3, Cluster 2

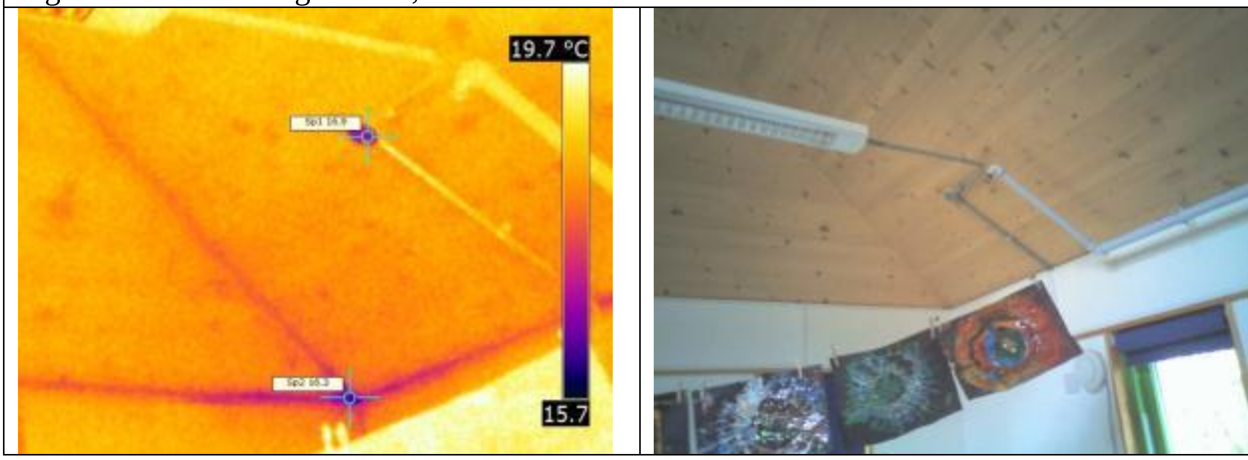


Figure 115 Air Leakage Test 3, Cluster 2

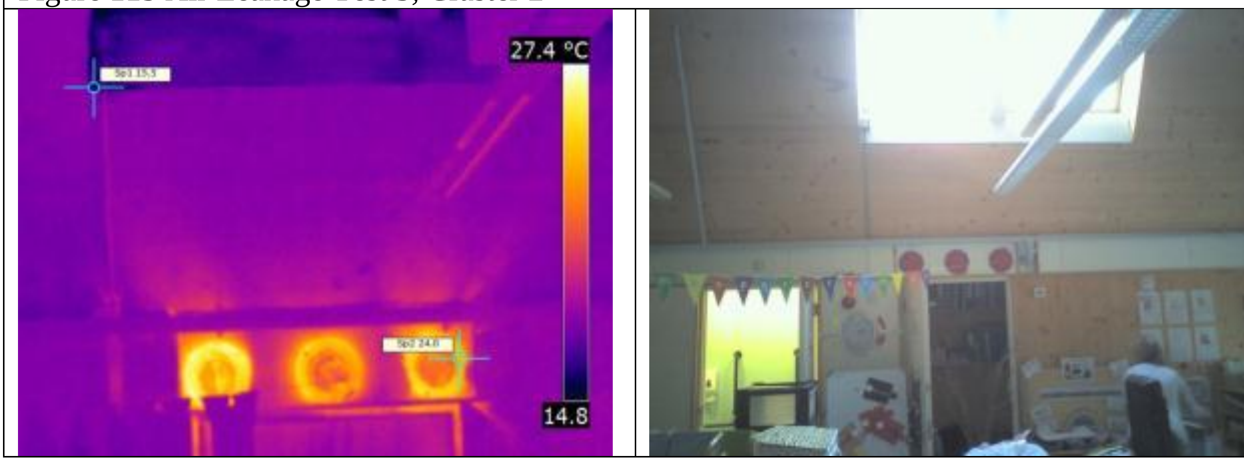
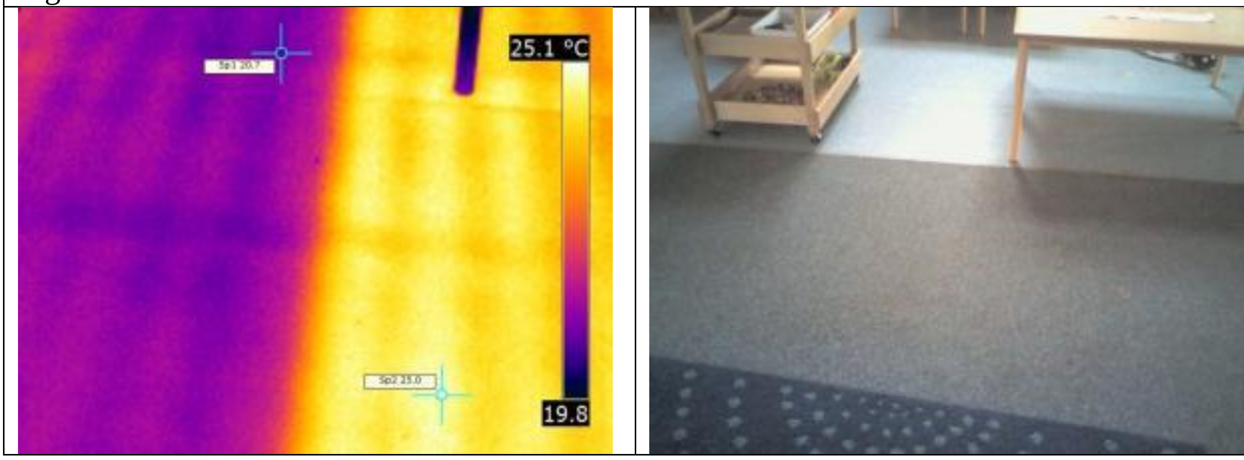


Figure 116 Air Leakage Test 3, Cluster 2

Underfloor Heating

Figure 117 Cluster 2



Technology Strategy Board
Driving Innovation

Appendix G: Air Leakage Tests

See attached file